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Maintenance of Supplies and Equipment
GUIDE TO RELIABILITY-CENTERED MAINTENANCE

Summary. This pamphlet covers the method and procedures for performing reliability-centered maintenance (RCM). It is to be used with MIL-STD 1388-2A for developmental items or by itself for fielded equipment.

Applicability. This pamphlet applies to all U.S. Army Materiel Command (AMC) major subordinate commands (MSCs) having responsibility for research, development, acquisition, management, and maintenance of Army materiel throughout the system/equipment life cycle.

*This pamphlet supersedes DARCOM-P 750-16, 6 June 1980.

Foreword

With the emergence of the Boeing 747 aircraft, the US airlines determined that aircraft maintenance would require considerable change from that required for prior equipment due to immense scheduled maintenance cost increases. Therefore, the airline operators collectively organized a study group in July 1968 to layout methodology to resolve the problem. The first group was referred to as Maintenance Steering Group No. 1 (MSG-1).

As more wide-body aircraft such as the L1011 and DC-10 emerged, the airlines continued to update their maintenance program efforts. The second effort was referred to as MSG-2. A third document, MSG-3, was developed to incorporate maintenance task analysis including frequency. This approach to maintenance enabled the airlines to realize major reductions in overall operations and support costs, with no degradation in reliability or safety.

Through the issuance of Program Objective Memorandum (POM) 78-82, the Army established the requirement that the MSG-2 concept, under the title Reliability Centered Maintenance (RCM), be incorporated on all Army weapon systems/ equipment.

This pamphlet has been written to help you prepare and implement the RCM program as directed in the policies of DOD D 4151.16, AR 750-1, AR 700-127, AR 70-1, and MIL-STDs-1388. Through the proper use of RCM procedures, a viable and realistic scheduled maintenance program can be developed.

CHAPTER 1

INTRODUCTION

1-1. Purpose. This pamphlet is a guide for Army representatives and contractors who write and develop a detailed maintenance plan for system/equipment using the Reliability-Centered Maintenance (RCM) philosophy. It explains in detail how to use the RCM logic and the failure mode, effects and criticality analysis (FMECA) to develop a scheduled maintenance plan which includes the maintenance task and the maintenance interval for preventive maintenance checks and services (PMCS) and provides information for overhaul, age exploration, economic analysis, and redesign.

1-2. References. Required and related publications are listed in appendix A.

1-3. Explanation of abbreviations and terms. Abbreviations and special terms used in this pamphlet are explained in the glossary.

1-4. Your role in developing the Maintenance Plan.

a. RCM analysis is used to obtain the detailed maintenance plan which provides the basis for the scheduled maintenance workload for the system/equipment. It is an integral component of Logistic Support Analysis (LSA) and continues for the life cycle of the equipment/system (AR 700-127).

b. You, as the Army representative, should ensure that the RCM requirements appear in the Integrated Logistic Support Plan (ILSP) of the program management document (PMD) with the appropriate documentation and milestones (AR 700-127). The effort does not end with input to the ILSP. The plan must be updated and the information must be transferred to the contract during the concept exploration phase and continued for the life of the equipment/system.

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CHAPTER 2

LOGISTICS SUPPORT ANALYSIS (LSA) PROCESS

2-1. Introduction. LSA is initiated in the concept exploration phase and is continued through the demonstration and validation, full-scale development, and production and deployment phases. It is a systematic, comprehensive analysis that is conducted in accordance with MIL-STD 1388-1A. This analysis is a composite of systematic actions to identify, define, analyze, quantify, and process logistic support requirements to achieve a balance among materiel readiness and capability, reliability, maintainability, vulnerability, survivability, operating and support costs, hardware costs, and the system's logistics requirements. These requirements are identified in DOD Directive 5000.39 and AR 700-127 as the elements of ILS. (See fig 2-1)

(1) Design influence and integration to include logistics-related reliability (R) and maintainability (M).

(2) Maintenance plan.

(3) Manpower and personnel.

(4) Supply support.

(5) Support equipment and test, measurement and diagnostic equipment.

(6) Training and training devices.

(7) Technical data.

(8) Computer resources support.

(9) Packaging, handling, and storage.

(10) Transportation and transportability.

(11) Facilities.

(12) Standardization and interoperability (formerly RSI) (AR 700-127)

Figure 2-1. ILS Elements

These elements represent the logistics support resources required by the Army in the field to maintain a materiel system in operationally ready condition. As the LSA evolves, the number and type of iterative analyses vary according to the program schedule and design complexity. RCM is just one iterative analysis with the results documented in the Logistic Support Analysis Record (LSAR) (MIL-STD 1388-2A).

2-2. Materiel Acquisition Life Cycle. The acquisition life cycle of a system/equipment is the total life span commencing with the program initiation and extending through the operational phase to its eventual retirement from the inventory. The life cycle concept of materiel is an attempt to present a logical event-oriented model of the typical acquisition program to aid managers in planning, scheduling, and executing hardware and logistics support acquisition. The four phases correspond to increasing levels of resource commitment which requires decision review by higher authority prior to the new commitment.

a. Concept exploration phase. This phase of the acquisition process explores and identifies alternative system concepts. This will be generally accomplished by a special task force or special study group. Several studies will be initiated in this phase prior to and in support of developing a Letter of Agreement (LOA) and an acquisition strategy as documented in the Systems Concept Paper (SCP). The concept formulation package consists of four elements: Trade-Off Determination (TOD); Trade-Off Analysis (TOA); Best Technical Approach (BTA); and Cost and Operational-Effectiveness Analysis (COEA). The development of the ILS Plan begins the initial planning effort for logistics support planning.

b. Demonstration and validation phase. This stage transforms the conceptual design into a practical design criteria suitable for hardware development. If necessary the design is evaluated with advance development models. The technical data base and the contract documentation package for full-scale development of the system are prepared. This phase implements the logistic support planning started in concept exploration phase. The PMD is updated and records program decisions and provides appropriate analysis of technical options, manpower, and logistics requirements and goals, testing, and financial management. The requirements of the logistic support planning become part of the advance development (usually contract) and the analyses required from the ILS plan and LSA program are documented and later verified through developmental testing and operational testing I (DT/OT I). The results are then used to update the PMD which contains the Logistic Support Plan.

c. Full-scale development. This phase transforms the design concept that was validated in the preceding phase into engineering development models. Logistic and maintenance support requirements are validated as described in the ILS Plan. Conformance to specified requirements for support equipment, tools, technical data, support items, training, manpower, and other support elements dictated by analysis of the design is accomplished. Trade-offs have been conducted to determine the best balance among hardware characteristics, support concepts, support resources requirements, and life-cycle costs.

d. Production and deployment. Analysis, test, and evaluation results, and independent reviews have affirmed that the maintenance plan and planned manpower and other logistics support resources are adequate to meet peacetime readiness and wartime deployment goals. Manufacturing processes and tooling, inspection, and test procedures, and management control techniques are designed specifically for manufacture of the production baseline for delivery to the Army user. This phase involves the establishment of an effective support base, performing required training, and problem resolution through feedback mechanisms for the entire service life.

2-3. The relationship between LSA and RCM. The development of an item/system requires the interface of many of the logistic support disciplines such as design, reliability, maintainability, human engineering and cost estimating. Any change or decision as a result of an analysis in one of the disciplines may affect all of the other resultant analyses. Therefore, a change in any one discipline may cause a ripple effect on the total logistics support program and each of the separate program areas must be constantly reviewed for any impact in their respective areas. Figure 2-2 shows the systems logistic support analysis interfaces for applicable tasks called for in MIL-STD 1388-1A. The RCM analysis is performed as part of the Functional Requirements Identification (Task 301) in MIL-STD 1388-1A and is documented in Data Record B (Item Reliability (R) and Maintainability (M) Characteristics) of the LSAR (MIL-STD 1388-2A). The LSAR Output Report LSA-050, RCM Summary, provides the results by task code for any maintenance level or safety hazard code for which RCM has been accomplished. This does not end the requirement to continually update the analysis because of changes in one of the disciplines or as a result of later analysis (trade-off analyses (Task 303); or task analysis (Task 401)) which are performed to determine the best system (support, design and operation) which satisfies the need with the best balance among cost, schedule, performance, and supportability.

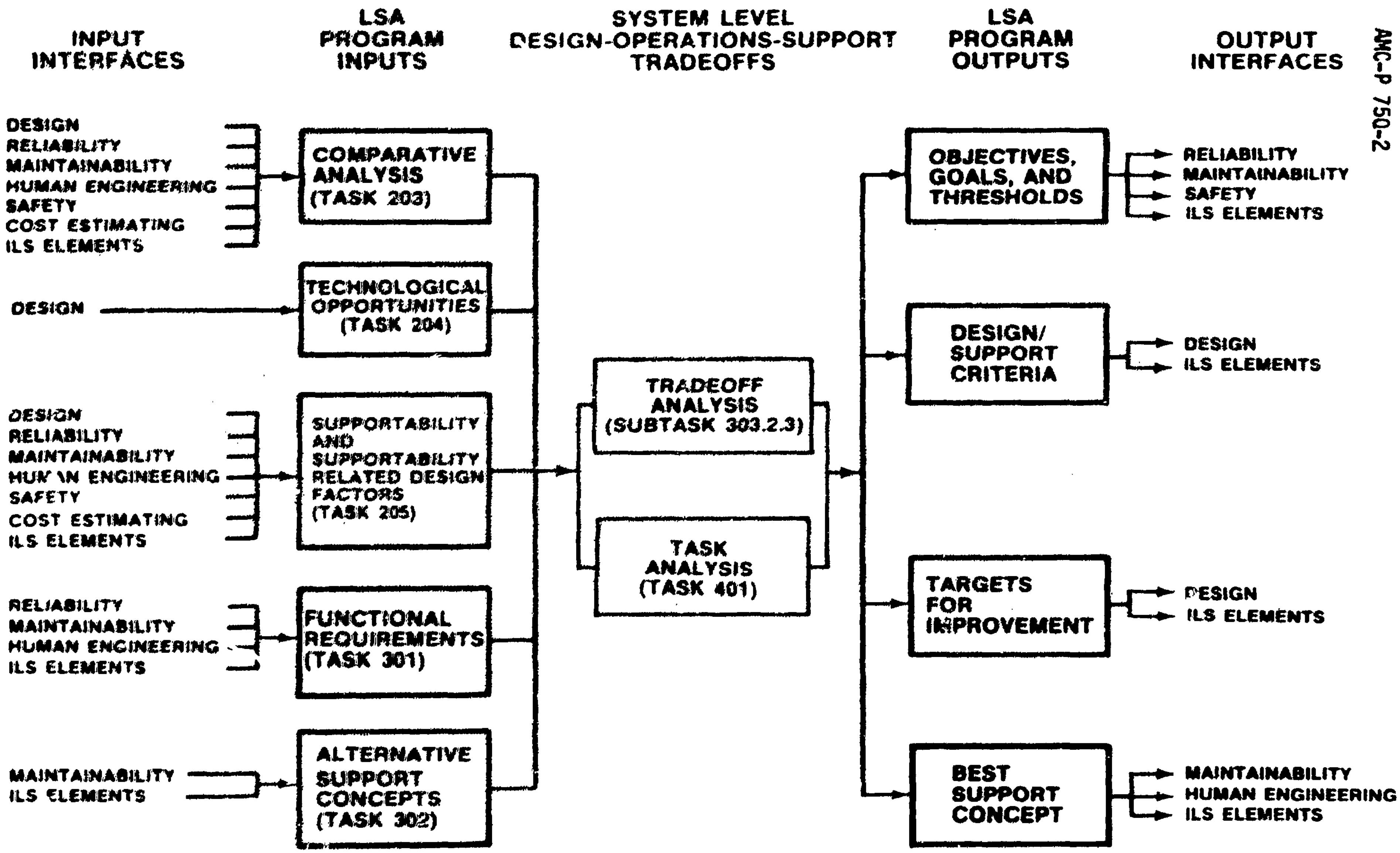

Figure 2-2. Relationship between LSA and RCM

CHAPTER 3

REQUIREMENTS APPLICATION

3-1. The Maintenance Plan.

a. The maintenance plan describes the requirements and tasks to be accomplished for achieving, restoring, or maintaining the operational capability of a system or an item of equipment. It is a concise, narrative summary of maintenance requirements that must be performed for weapon and other systems, subsystems, equipment and support equipment. A well-developed maintenance plan will prevent deterioration of the inherent design levels of reliability with a minimum expenditure of maintenance and support resources. Maintenance cannot correct design deficiencies nor improve inherent levels of reliability provided by design. Therefore, an important aspect of the maintenance plan development is the early identification and correction of design deficiencies that will affect the maintenance plan and its resource requirements. The implementation of the maintenance plan developed for a system or equipment, along with all attendant procedures, controls, data collection and reporting, and ILS element resource requirements, is known as a maintenance program.

b. The maintenance plan establishes and delineates the repairable components and maintenance requirements of a system, subsystem, or item of equipment. For each repairable component, the maintenance plan identifies the maintenance level authorized to perform the preventive or corrective maintenance tasks required, and all necessary system or equipment servicing requirements. The maintenance plan identifies the support equipment requirements and supply support requirements that are necessary to perform the indicated preventive maintenance, corrective maintenance, servicing, or calibration task.

c. The maintenance plan for a weapon system or item of support equipment evolves from maintenance concept alternatives through the systematic application of specific and well-defined analytical steps. These steps are successively iterated during the full scale development phase of a weapon system acquisition. These steps form an analytical process that is a function of maintenance planning and engineering, and is called the maintenance planning and analysis process.

d. Maintenance planning is an element of the logistics support analysis process as described in MIL-STD 1388-1A. It is a principal source for the development and documentation of ILS element requirements. As an integral part of the LSA process, maintenance planning initially strives to establi... concepts and goals, in the form of maintenance characteristics, that should be achieved by the proposed system or equipment. Throughout the program initiation and full-scale development phases of program development, maintenance planning data are documented in the LSA records, forming a data base to reflect the current state of proposed maintenance tasks. By analyzing the evolving design of the LSA candidates, and by describing the maintenance requirements in the form of tasks, to increasingly lower indenture levels, the resulting ILS element resource requirements are developed. Where RCM analysis is interested in the failure relationship between equipment/system age vs. reliability, there is a need for

age exploration analysis. This process is closely related to the development of preventive maintenance requirements. Age exploration is also used to validate preventive maintenance requirements and parameters by supplementing the initial RCM evaluation. Maintenance planning data, documented as part of the LSA process, provide the basis for detailed definition of the maintenance plan.

3-2. Maintenance Requirement Categories.

a. Maintenance requirements are categorized as either preventive maintenance, corrective maintenance, servicing, or calibration requirements. Except for some servicing and calibration categories, maintenance requirements are traceable to a failure mode effects and criticality analysis (FMECA). The FMECA, with the corresponding reliability and maintainability analysis, is the starting point for the analysis needed to develop maintenance requirements and tasks through all levels of maintenance, including depot.

b. Preventive maintenance analysis uses reliability centered maintenance (RCM) logic to develop preventive maintenance requirements. RCM refers to a scheduled maintenance program designed to realize the inherent reliability characteristics of weapon and other systems, and equipment items, including support equipment. Scheduled (preventive) maintenance should be considered for any item whose loss of function or mode of failure could have safety consequences. Scheduled maintenance also should be considered for any item whose functional failure will not be evident to the operator or operating crew, and therefore, cannot be reported for corrective maintenance action. In all other cases, the consequences of failure are either economic or operational, and scheduled tasks directed at preventing failures must be justified on these grounds. An RCM analysis program, leading to the identification of all preventive maintenance requirements, includes only those tasks that satisfy the criteria for both applicability and effectiveness. The applicability of a task is determined by the characteristics of the item, and its effectiveness is defined in terms of the consequences the task is designed to prevent. General and detailed RCM requirements are covered in chapter 4 of this pamphlet.

c. Related to the development of preventive maintenance requirements is the requirement for age exploration analysis on items for which RCM analysis is concerned with establishing a failure relationship between age and reliability. It is also used to validate preventive maintenance requirements and parameters, building on the initial evaluation. In the early stages of a weapon system or support equipment life cycle, during the period when preventive maintenance tasks are being developed, this age-reliability relationship may not be perfectly understood. This causes conservative estimates of the frequency of scheduled task performance. As operating experience is gained, this information is used as a basis to adjust the time periods for scheduled maintenance and to validate the overall preventive maintenance program. This early age exploration analysis requirement produces the initial data to establish time intervals and planning for the follow on age exploration. This program is planned during initial evaluations, begun during test and evaluation, and continued when the weapon system, equipment or support equipment are fielded. Age exploration is covered in greater detail in chapter 7.

d. Corrective maintenance analysis is performed to determine significant, detailed corrective maintenance tasks that are required for each repairable item down to the replacement component for each level of maintenance under consideration. During corrective maintenance analysis, two objectives are realized; the equipment design is assessed in order to evaluate its reliability and maintainability characteristics, and tentative maintenance levels for maintenance requirements task, as well as tentative support equipment, are identified. (Undesirable characteristics are identified as design problems and are reported to the design team for correction or improvement.) Corrective maintenance tasks are then subjected to task, skill, and time-line analysis.

e. Servicing requirements analysis is performed to determine those tasks necessary to replenish consumables expended during equipment usage or during operation of support equipment. Such consumables may include fuel, oil, grease, graphite, oxygen, or other fluids or stores required for the normal operation of the equipment or support equipment. Servicing requirements are separate and distinct from preventive maintenance tasks that may be required to check stores or various fluid levels prior to operation. Servicing requirements are developed through an analysis of system and equipment operational requirements. Servicing requirements, like all other maintenance requirements, are subjected to both task and skills analysis, and time line analysis. These analyses are necessary to determine the appropriate logistic element planning constraints.

f. Calibration analysis is the detailed evaluation of a system, subsystem, or item of support equipment that is performed to develop measurement parameters that are required prior to establishing a comprehensive calibration program. This includes measurement ranges, accuracy requirements, and the calibration interval required for each level of measurement, with the basic level being when the system under analysis, and its support equipment, are fully operational. Each succeeding level then requires a greater degree of accuracy than its predecessor. The primary objective of calibration analysis is to then identify the manpower and support equipment requirements necessary at each level of measurement.

g. Task and skills analysis identifies the technical tasks that will be performed by maintenance personnel. The analysis is designed to provide necessary data to identify manpower requirements for the proper maintenance and repair of systems or equipment items and support equipment in accordance with their mission, employment concept and doctrine, personnel constraints, and the approved logistic support concept. It specifically yields quantitative data concerning required skills, time intervals necessary to accomplish tasks, and manpower required. The task and skills analysis also provides descriptive data on the specific task steps required for the accomplishment of each specified maintenance or operational requirement. As part of the task and skills analysis, most resources (including special tools) required for the performance of each task step are identified and aggregated for subsequent use. The need for additional training of existing skills, training equipment, and training aids is also first identified in the task and skills analysis. These source data are directly auditable to the required level of maintenance and personnel requirements.

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CHAPTER 4

RELIABILITY-CENTERED MAINTENANCE (RCM) APPLICATION AND LOGIC

4-1. RCM Background.

a. The procedures presented in this pamphlet represent an evolution from the procedures developed in July 1968, by representatives of various airlines which constituted the Maintenance Steering Group Number 1 (MSG-1). This group developed decision logic and intra-airline/aircraft manufacturer procedures for developing scheduled maintenance programs for the Boeing-747 aircraft. Subsequently, these procedures were refined. and Boeing-747 peculiarities were deleted, to make a more universal document titled "Airline Manufacturer's Maintenance Program Planning Document - MSG-2."

b. The potential value of the MSG-2 concept to the Department of Defense was acknowledged by the Secretary of Defense in his annual Defense Department report for FY-76, citing the success of the Navy application of MSG-2 on the P-3 aircraft program. DOD direction was subsequently provided to the services to apply the MSG-2 concept to new aircraft entering service in FY-77, to in-service aircraft by the end of FY-79, and to all other military equipment by the end of FY-79. The Department of the Army (DA) implementation of the MSG-2 concept is called RCM. This pamphlet provides guidelines for application of RCM on developmental and fielded systems as part of the LSA process and incorporates a logic similar to "Airline Manufacturer's Maintenance Program Planning Document - MSG-3," which is similar to MSG-2, but is maintenance-task-oriented.

4-2. RCM Objectives.

a. An efficient maintenance analysis and planning program is designed to meet the following objectives--

(1) To establish design priorities which facilitate preventive maintenance.

(2) To plan preventive maintenance tasks that will restore safety and reliability to their inherent levels when equipment/system deterioration has occurred.

(3) To obtain the information necessary for design improvement of those items whose inherent reliability proves inadequate.

(4) To accomplish these goals at a minimum total cost, including maintenance costs and the costs of residual failures.

b. These objectives recognize that maintenance programs, as such, cannot correct deficiencies in the inherent safety and reliability levels of the equipment. The maintenance program can only optimize the operational input of such inherent levels, and if they are found to be unsatisfactory, design modification is necessary to obtain improvement.

4-3. Concept.

a. The maintenance plan for a system/equipment is a description of the requirements and tasks to be accomplished for achieving, restoring, or maintaining the operational capability of the system/equipment. The maintenance plan evolves from the iterations of the LSA to identify the maintenance concept, reliability and maintainability parameters and requirements, maintenance tasks, descriptions of maintenance organizations, support and test equipment requirements, maintenance standards, supply support requirements, and facility requirements.

b. Maintenance plan determination must recognize the interrelationships between the LSA tasks contained in MIL-STD-1388-1A and other system engineering disciplines such as the reliability, maintainability, safety, standardization, and human engineering programs. Efficient maintenance planning requires input from and output to these related disciplines.

c. This pamphlet will concentrate on that portion of maintenance planning that requires determination of maintenance requirements in the form of scheduled maintenance tasks. This step in the overall determination of the detailed maintenance plan provides the basis for the scheduled maintenance workload for the system/equipment and impacts the ability to sustain the inherent reliability of the system and its components and maintain adequate safety levels.

d. Inherent to the maintenance planning process, as with other LSA tasks, is the identification of logistics support problems and risks, and development of the required data to support trade-off analyses with design personnel. The guidelines presented are structured to identify areas for design review and trade-offs in addition to the identification of scheduled maintenance tasks requirements.

4-4. Maintenance Planning. Maintenance plan development is initiated during the conceptual phase of program development as part of the logistic support analyses to identify alternative support concepts; reliability, availability, maintainability, and initial life-cycle support cost goals, and potential logistic problems. From this broad base, the detailed maintenance requirements and tasks are identified and tested during the validation and full-scale development phases of the life cycle as the baseline logistic support concept is established and hardware design progresses. The finalized plan is reflected by the maintenance allocation chart (MAC) contained in the organizational level maintenance manual for the system/equipment. The overall relationship of RCM process is graphically depicted in figure 4-1.

4-5. Scheduled Maintenance Program Tasks.

a. An efficient program is one which identifies the scheduled maintenance tasks and realistically schedules only those tasks necessary to meet stated objectives. It does not schedule additional tasks which will increase maintenance costs without a corresponding increase in reliability/availability.

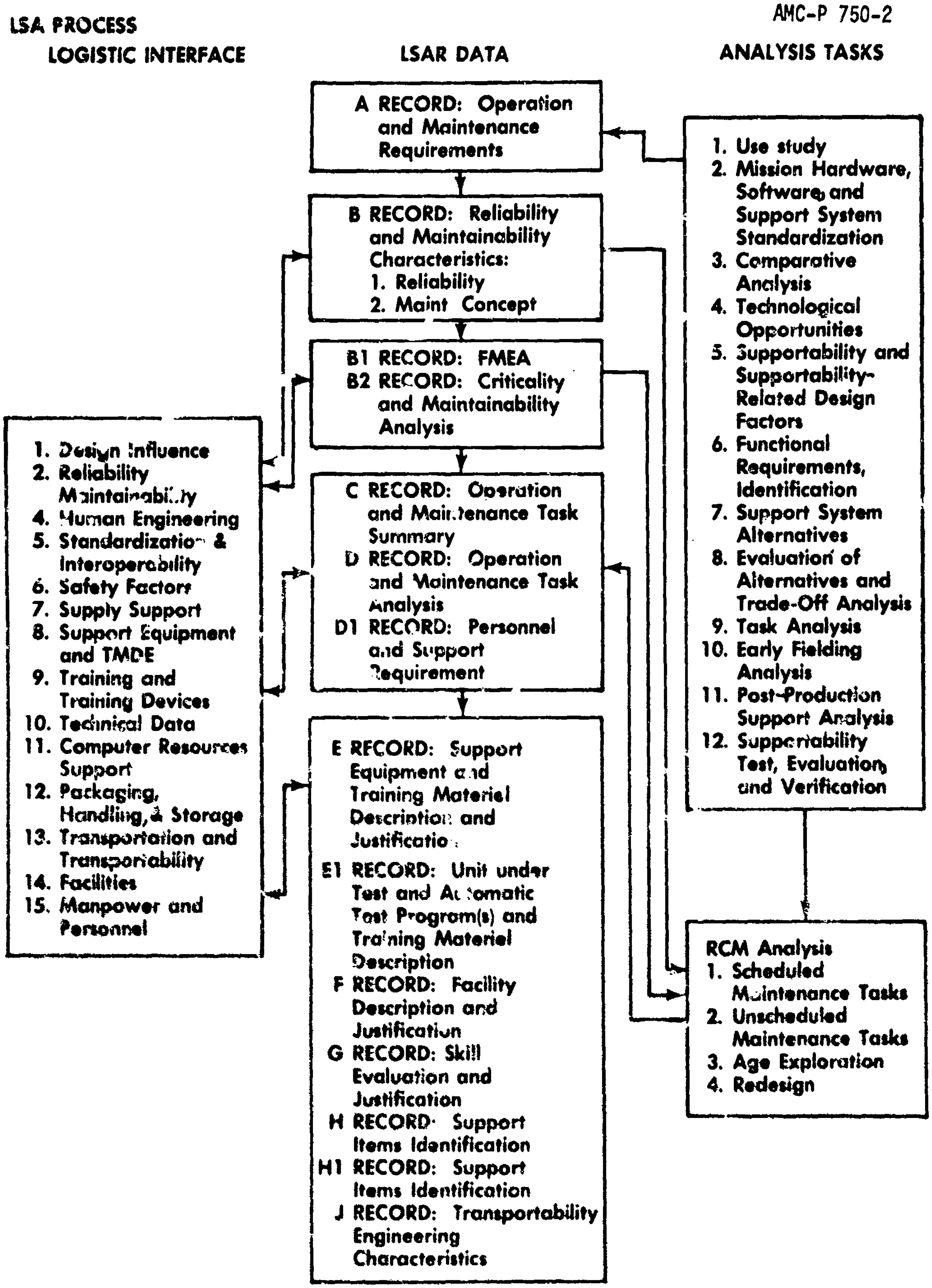

Figure 4-1. RCM in the LSA Process

b. The objective of scheduled maintenance tasks is to prevent deterioration of the inherent safety and reliability levels of the equipment or to reduce the life-cycle costs.

The tasks in a scheduled maintenance program may include --

(1) Lubrication/servicing.

(2) Operator/crew monitoring.

(3) Operational checks.

(4) Inspection/functional check.

(5) Adjust/align/calibrate.

(6) Remove/replace.

(7) Overhaul.

4-6. Failure Mode, Effects, and Criticality Analysis (FMECA).

a. MIL-STD-1629 provides the procedures for performing a failure mode, effects, and criticality analysis. FMECA is an essential function in design from concept through development. To be effective, the FMECA must be iterative to correspond with the nature of the design process itself. The extent of effort and sophistication of approach used in the FMECA will be dependent upon the nature and requirements of the individual program. This makes it necessary to tailor the requirements for an FMECA to each individual program. Tailoring requires that, regardless of the degree of sophistication, the FMECA must contribute meaningfully to program decisions. A properly performed FMECA is invaluable to those who are responsible for making program decisions regarding the feasibility and adequacy of a design approach.

b. The usefulness of the FMECA as a design tool and in the decisionmaking process is dependent upon the effectiveness with which problem information is communicated for early design attention. Probably the greatest criticism of the FMECA has been its limited use in improving design. The chief causes for this have been untimeliness and the isolated performance of the FMECA without adequate inputs to the design process. Timeliness is perhaps the most important factor in differentiating between effective and ineffective implementation of the FMECA. While the objective of an FMECA is to identify all modes of failure within a system design, its first purpose is the early identification of all catastrophic and critical failure possibilities so they can be eliminated or minimized through design correction at the earliest possible time. Therefore, the FMECA should be initiated as soon as preliminary design information is available at the higher system levels and extended to the lower levels as more information becomes available on the items in question.

c. Although the FMECA is an essential reliability program task, it also provides information for other purposes. The use of the FMECA is called for in maintainability, safety analysis, survivability, and vulnerability, maintenance plan analysis, and for failure detection and isolation subsystem design. This coincident use must be a consideration in planning the FMECA effort within the same contractual program and is a critical element of LSA/LSAR.

4-7. RCM Logic - General.

a. The RCM logic presented in figure 4-6 is designed to accomplish the following--

(1) Using data from the system safety and reliability programs, identify components in the system/equipment which are critical in terms of mission or operating safety.

(2) Provide a logical analysis process to determine the feasibility and desirability of scheduled maintenance task alternatives.

(3) Highlight maintenance problem areas for design review consideration.

(4) Provide the supporting justification for scheduled maintenance task requirements.

b. The RCM logic provides a more rational procedure for task definition and a more straightforward and linear progression through the decision logic. It takes a "from the top down" or consequence of failure approach. At the outset, the functional failure is assessed for consequence of failure and is processed for one of four basic categories--

(1) Catastrophic.

(2) Critical.

(3) Marginal.

(4) Minor.

The four catagories are identified as Safety Hazard Severity Codes (SHSCs) 1 - 4. With the consequence category established, only those task selection questions pertinent to the category need be asked. This eliminates unnecessary assessments and expedites the analysis. A definite applicability and effectiveness criteria has been developed to provide a more rigorous selection of tasks. In addition, this approach helps to eliminate items from the analytical procedure whose failures have no significant consequence.

c. The logic process is based upon the following--

(1) Scheduled maintenance tasks should be performed for noncritical (category 3 and 4) components only when performance of the scheduled task will reduce the life-cycle cost of the equipment/system.

(2) Scheduled maintenance tasks should be performed on critical components (category 1 and 2) when such tasks will prevent a decrease in reliability or deterioration of safety to unacceptable levels, or when the tasks will reduce the life cycle cost of ownership of the system/equipment.

d. The RCM logic is intended for application once a component's failure modes, effects, and criticality have been identified. As with other LSA tasks, the logic process will be reapplied as available data moves from a predicted state to measured values with a higher degree of certainty, and as design changes are made. In addition, once all components have been subjected to the logic process, an overall system analysis is required to arrive at the overall maintenance plan. This system analysis merges individual component requirements into a system maintenance plan by optimizing the frequency of scheduled maintenance requirements and the sequence of performance of individual scheduled tasks.

e. The RCM logic will be applied to each reparable item in the system/equipment. The maintenance task requirements will be identified against the reparable components; however, individual failure modes must be addressed during the application of the RCM logic. Thus, for a given component, different scheduled tasks could be arrived at due to the different failure modes and their characteristics. As an example, a given component might undergo crew monitoring during normal operations to detect the majority of predicted failure modes for the component, while still having a scheduled inspection requirement due to a failure mode that is not detected during routine operator/crew monitoring.

f. In addition to the scheduled maintenance task requirements identified during application of the RCM logic, any scheduled tasks that were assumed in establishing the reliability characteristics of the system/equipment under the reliability program must be included in the maintenance plan. Inherent failure rates and failure modes and effects may need adjusting if an assumed scheduled maintenance action is omitted from the maintenance plan after application of the RCM logic. For example, the reliability data provided for an internal combustion engine and its internal components may be based on a 6,000-mile scheduled oil and oil filter changes. If this schedule is changed because of Army oil analysis in developing the detailed maintenance plan for the engine, the resulting effect on the reliability parameters must be determined.

g. When determining if a failure is critical for mission considerations, the mission of an individual piece of equipment will be the governing factor. Thus, for a missile component, the individual missile is addressed, not the complete missile system composed of many launchers and missiles.

h. Task determination questions are arranged in a sequence so that the most preferred task, most easily accomplished, is considered first. Potential tasks are considered in sequence down to and including possible redesign.

i. The logic is maintenance-task-oriented and not maintenance-process-oriented. By using the task-oriented concept, one will be able to see the entire maintenance program reflected for a given item (e.g., an item may show a before

operation inspection, a lubrication task at a monthly interval, and an align on a quarterly basis). Servicing/lubrication is included as part of the logic diagram since this ensures that an important task category is considered each time an item is analyzed.

j. The selection of maintenance tasks as output from the decision logic has been enhanced by a clearer and more specific delineation of the task possibilities contained in the logic.

k. Treatment of hidden functional failures is more thorough as the logic provides a distinct separation between tasks applicable to either hidden or evident functional failures.

l. The effect of concurrent or multiple failure is considered Sequential failure concepts are used as part of the hidden functional failure assessment and multiple failure is considered in structural evaluation.

m. There is a clear separation between tasks that are economically desirable and those that are required for safe operation.

4-8. Disposition of RCM Analysis. During the analysis, the logic leads the analysts to make a decision on disposition of each failure mode under consideration. Block 5B, card number B11 of Data Record B is the location for recording the disposition (fig 4-3). The card columns are coded A through E and the meanings for each are as follows--

Card Column	Meaning
A	Economics dictates that scheduled (preventive) maintenance is the only possible decision
B	Scheduled (preventive) maintenance
C	Unscheduled (corrective) maintenance
D	Age exploration
E	Redesign

a. Card column A will be marked "Y" if economic analysis (decision 4 of logic) indicated that scheduled maintenance is more economical than allowing the failure, or that a scheduled inspection/test for failure is more economical than redesign. This entry is intended to show that economics was the only factor that qualifies this entry for scheduled (preventive) maintenance.

b. Card column B will be marked "Y" if one or more of logic decision 10, 11, 12, 13, 14, or 15 is marked "Y". This entry will show that economics was not a determining factor in qualifying this entry for scheduled (preventive) maintenance.

c. Card column C will be marked "Y" for any failure mode for which unscheduled (corrective) maintenance is either more economical (decision 4) or acceptable from mission or safety considerations (decision 9).

d. Card column D will be marked "Y" if age exploration is applicable and effective (decision 16) and must be accompanied by one of the other dispositions.

e. Card column E will be marked "Y" to indicate that redesign (decision point 17 of logic) has been considered and is a valid alternative. The use of the disposition card columns are for the LSAR output report, LSA 50 report (RCM Summary), which summarizes the scheduled maintenance required by task code, maintenance level, and safety hazard severity code (SHSC) of Card B13 of Data Record B1 (fig 4-4). This is then used by management or the analyst to make important decisions covering the maintenance plan, which addresses personnel requirements, reliability (readiness), tools and test equipment, and maintenance (see chap 5). This is done by comparing the results to the requirements listed in the LSAR Data Record A for scheduled maintenance (fig 4-2).

4-9. RCM Logic - Detailed.

a. The RCM logic displayed in figure 4-6 is used to determine if a component should have a scheduled (preventive) maintenance requirement, and, if so, what scheduled maintenance tasks should be performed. Each decision point is numbered and detailed instructions for each are provided below. The decision point number, the subparagraph number of para. 4-9,b, and the element number of block 5A of the B11 card of LSAR Data Record B are the same, i.e., decision 12, paragraph 12, and element 12 of block 5A all refer to the same transaction. A B11 card will be completed for each failure mode identified on Card B13 of the B1 data record (fig 4-3).

b. The following is a detailed set of instructions for application of the logic in figure 4-6.

(1) Decision 1. Is functional component failure critical for safety or mission? This question will be asked for each failure mode identified on Data Record B1 for the component under analysis. The answer to this question will be based on the Failure Modes and Effects Analysis (fig 4-4 - LSAR Data Record B1) and the Criticality and Maintainability Analysis (fig 4-5 - LSAR Data Record B2). A "yes" answer indicates that this failure mode exists and has been identified as critical or catastrophic which corresponds to a safety hazard severity code (SHSC) of 1 or 2 and will result in a safety hazard or possible serious mission impact. Components and failure modes for which a "yes" answer is obtained will be referred to as critical. These critical items will be analyzed further to determine if a scheduled maintenance task will help prevent deterioration of reliability or safety levels, thus minimizing the risk of a possible serious mission impact or safety hazard. A "no" answer indicates that the component is classified with a SHSC of 3 or 4 and further exploration is required to determine if scheduled maintenance is required for secondary failures which are critical, have hidden failures, or have economical impact. The appropriate entry will be made on Data Record B, card B11, block 5A in card column 1.

(2) Decision 2. Does failure cause secondary failure that is critical for safety or mission? The instructions for this decision point are the same as for decision 1, but this question refers to secondary failures that are caused by the primary failure modes considered in decision 1. A "yes" answer identifies a noncritical failure mode which causes a secondary failure classified as critical and results in either a safety hazard or a mission abort. (See multiple failure chap 5.) The failure mode will be analyzed further to determine what scheduled maintenance tasks can be performed that will prevent or decrease the likelihood that reliability or safety will deteriorate below acceptable levels. A "no" answer to each question in decisions 1 and 2 indicates that the failure mode for the component is noncritical and may be operated to failure without incurring a safety hazard or a mission abort. The appropriate entry will be made on Data Record B, card number B11, block 5A, card column 2.

(3) Decision 3. Is failure hidden? The question in this decision point is addressed to identify whether the operator/crew will be aware of the loss (failure) of a function during the performance of their normal operating duties. This is the last question to segregate the failure mode under consideration into one of two categories: (a) the need for scheduled maintenance task to preserve reliability or safety· (b) scheduled maintenance task based solely upon economics. A "yes" answer indicates that the functional failure is hidden from the operator/crew. A "no" answer indicates that the component is noncritical and can be operated to failure without incurring a safety hazard or a mission abort. For these components, decision point will be addressed to determine if a scheduled maintenance task is justifiable from the economic standpoint. The appropriate entry will be made on Data Record B, card B11, block 5A, card column 3.

(4) Decision 4. Does economic analysis indicate scheduled maintenance?

(a) Decision point 4 identifies scheduled tasks which can be performed and that will decrease the cost of ownership of the end item. To address this decision point, it must first be determined whether a scheduled task can be done. This can be determined by applying the questions in decision points 5 through 17, in which decision points 10, 11, 12, 13, 14, and 15 identify the specific tasks. eep in mind that the questions are being addressed for noncritical failure modes. If economic analysis does not indicate scheduled maintenance, operate to failure, transaction 4a, and enter a "Y" in card column c. This completes the decisionmaking process for this failure mode.

(b) In determining if a scheduled maintenance task is economically justified, the difference in ownership cost for the end item must be calculated. It is not intended that a complete life-cycle cost be calculated for each alternative, but rather those cost factors which would be different between the alternatives should be determined. Consideration must also be given to any manpower, downtime, or availability constraints on the end item if an additional scheduled task is included in the maintenance plan for a noncritical component. If a substantial cost savings could be realized through some scheduled maintenance action which impacts one or more system constraints, then a trade-off analysis shall be performed. Refer to chapter 5 for discussion and determination of cost-effectiveness of scheduled maintenance tasks.

(c) This decision point should not be addressed until the RCM logic has been applied to the critical components of the system/equipment under analysis, because the results of the critical component analysis could affect the cost of feasible scheduled tasks on noncritical components. For example, a noncritical inspection may not be economically justifiable by itself if it requires excess time and cost, but if the time and cost are determined to be required for a critical component inspection, then the noncritical inspection may be economically justifiable. For this reason, the economic aspects of noncritical tasks should only be addressed after the scheduled maintenance requirements for critical components are determined.

(d) If the analysis shows that scheduled maintenance tasks on the noncritical component reduces the cost of ownership of the system/equipment, then this task(s) would be included in the overall maintenance plan, and in the disposition block 5B of card number B11 on Data Record B, enter a "Y" in the card column labeled A and enter the appropriate task code(s) in block 5E of the B11 card. If a scheduled task is not feasible or is not economically justified for the noncritical component under analysis, then the component would be operated to failure and only unscheduled maintenance would be performed. In the disposition block 5B of card number B11 on Data Record B, enter a "Y" in the card column labeled C and check card number B18 of Data Record B2 to ensure that the corrective maintenance task identified as a result of the FMECA, has been entered on card number B18. The appropriate entry will also be made on Data Record B, card B11, block 5A, card column 4.

(5) Decision 5. Can operator detect impending failure?

(a) This is the first of four decision points (5 through 8) that will determine if scheduled maintenance tasks are applicable and effective.

(b) The question at this decision point is intended to identify those critical failure modes which can be detected through routine operator/crew monitoring with sufficient leadtime to prevent a mission abort or safety hazard. If there is a high probability that the failure mode under analysis can be detected with sufficient leadtime before it will actually occur to prevent a mission abort or incurrence of a safety hazard, then the question will be answered "yes." (Chap 6 discusses this in more detail.) This will be the case for failure modes which have a sufficient time difference between onset of initial degradation and actual failure, and a means of detecting the onset. The detection means can be in the form of instrumentation (gauges, warning lights, etc.) or operational characteristics (vibration, sound, etc.). The question will be answered "no" if the operator/crew cannot detect an impending failure, or if the time difference between onset and actual failure is not long enough to prevent a mission abort or safety hazard. The appropriate entry will be made on Data Record B, card B11, block 5A, card column 5.

(6) Decision 6. Can maintenance detect impending failure?

(a) The question at this decision point is addressed to identify the potential efficiency of a scheduled maintenance task on the component under analysis and must be considered in two parts. First, the impending failure must

be physically detectable either by visual inspection, through use of test or measurement equipment. To be detectable, measurable physical properties of the component must change with the onset of degradation to allow identification of impending failure through comparison with normal properties.

(b) The second consideration is the probability that the scheduled maintenance task will coincide with the time between onset of degradation and the occurence of failure so that the impending failure will be detected and corrected before it occurs. As an example, a component which fails within seconds after the onset of any measurable degradation would not be a good candidate for a scheduled task. The probability that any reasonable inspection interval would result in the inspection occurring within the time between onset and failure is very small in this case; consequently, the payoff would be extremely small. On the other hand, if the time between measurable failure onset and actual failure occurrence was measured in days or months, then an inspection interval could be established which would result in a high probability of detecting the failure under analysis before it occurs. In answering this consideration, the failure distributions from the Reliability Program, data from a historical data review, and applicable test results must be analyzed.

(c) If the impending failure is measurable, and a reasonable maintenance task interval which results in an acceptable probability of detection can be established, then the question in Decision Point 6 would be answered "yes." If one of these considerations is not met, then Decision Point 6 would be answered "no." The appropriate entry will be made on Data Record B, card B11, block 5A, card column 6.

(7) Decision 7. Is there an adverse relationship between age or usage and reliability?

(a) The question at this decision point is to identify wearout type components and to determine the feasibility of scheduling replacement of the component under analysis. This question would be answered "yes" if the probability of component failure increases as calendar time or usage indicators (operating hours, miles, rounds, cycles) increase. For these items, a scheduled removal could be identified at a point in time or after a specified amount of usage when the probability of failure increases to an unacceptable level. Removal and replacement with a new item will return the probability of failure to its original level. This question will be answered "no" if the probability of failure is independent of either calendar time or usage. This is the case for components which exhibit an exponential failure rate.

(b) In answering the question of this decision point "yes," it should be noted that a means of measuring the interval between the scheduled replacements of the component be provided. If the component cannot be economically maintained, then the question at this decision point must be answered "no."

(8) Decision 8. Can failure be detected by crew?

(a) The question at this decision point is addressed to identify hidden functions where occurrence of the failure under analysis may go undetected until

the function is required. If the operator/crew cannot detect that a failure has occurred, maintenance inspections or tests may be required to ensure that a failure has not occurred and that there is a high probability the hidden function will be available when required.

(b) A "yes" indicates that the failure under analysis can be detected by the operator/crew and a "no" indicates that the maintenance task is required to detect the failure. The appropriate entry will be made on Data Record B, card B11, block 5A, card column 8.

(9) Decision 9. Is unscheduled maintenance acceptable?

(a) This begins the part of the analysis which determines whether maintenance should be scheduled and whether the design of the item is adequate to meet the requirements for maintenance. If the question is answered "no," continue to decision point 17.

(b) This decision point identifies components which have critical hidden failure modes with no means of detecting impending failure or reducing the probability of a failure. Actual failures are detectable by the operator/crew either at the time of occurrence or after occurrence so that unscheduled maintenance can be accomplished in the event of failure. The answer to this decision point is based upon the probability of failure, failure detection, rate, predictability and criticality which are found on the B1 and B2 LSAR data record. If the failure or effects of the failure can be tolerated, then enter a "Y" in card column 9 and card column C of disposition, and check card number B18 of Data Record B2 to ensure that the corrective maintenance task, identified as a result of the FMECA, has been entered on card B18. Also, if a scheduled operator/crew inspection/test is required to detect failure, enter "Y" in card column B of disposition and the appropriate task code under block 5E of card number B11. A "no" for this decision point indicates that the risks of incurring a mission abort or safety hazard or hidden failure would be unacceptable and that the only alternative is to redesign the component or interfacing components to eliminate the critical or hidden failure modes or to provide a means of detecting the impending failure. In some cases, the required redesign may involve the additon of a test point or a measurement device, while in other cases the cost of incorporating the redesign may be prohibitive or the redesign may not be technically feasible.

(10) Decision 10. Is scheduled inspect/test for failure acceptable?

(a) This decision point identifies components which have critical failure modes with no means of detecting impending failures, no wearout characteristics, and no means for the operator/crew to detect failures that have occurred. For components that fall into this category, a scheduled maintenance task must be indicated in the maintenance plan to detect failures that have occurred and to ensure that there is a high probability of the hidden function being available when required. The corrective action for this decision will be prescribed by the FMECA as an unscheduled maintenance action and be recorded on card number B18 of Data Record B2.

(b) Economic considerations are used as a basis for determining if the failure or its effects can be tolerated and the effects of the failure must be weighed against the potential cost of redesign. If the failure or its effects can be tolerated, enter a "Y" on Data Record B, card number B11, block 5A, card column 10, and, in block 5B (disposition), enter a "Y" in card column A.

(11) Decision 11. Is operator/crew monitoring applicable and effective? (NOTE: Applicable and effective, i.e., ensures reliability, improves safety, or is more cost-effective.)

(a) This begins the portion of the logic that determines which scheduled maintenance tasks are both applicable and effective (Decision Points 11-15). (Chap 5 defines applicable and effective as used in this logic tree.) Within each decision are at least two tasks that are listed in the descending order of preference. The same criteria will be used when evaluating the tasks within each decision point and when comparing each decision point with the others in this sequence. In certain instances, it may be necessary to perform more than one maintenance task either within one decision block or a combination of decision blocks. Even though a single task has been identified as applicable and effective, all other tasks within this sequence (Decision Points 11-15) must be considered to determine if a combination of tasks may be necessary to maintain the inherent reliability of an item. The objective of this process is to optimize the maintenance program while minimizing the maintenance resources requirements.

(b) This decision point identifies critical components that exhibit wear out characteristics and impending failures that can be detected by routine operator/crew monitoring. This decision point is only entered with a "yes" answer to decision point 5. For all tasks identified, operator/crew monitoring is preferred. As the analysis proceeds through the logic, additional tasks may be identified that are applicable and effective. Pertinent remarks about the final selection of the scheduled maintenance tasks will be entered on card number B12, Data Record B of the LSAR.

(c) A "yes" answer indicates that operator/crew monitoring is applicable and effective and would provide an acceptable level of reliability and safety at the least cost. An "N" would indicate that operator/crew monitoring does not maintain the required reliability and safety levels. The appropriate entry will be made on Data Record B, card B11, block 5A, card column 11.

(d) A "yes" answer to question 11, 12, 13, 14, or 15 indicates that scheduled (preventive) maintenance is applicable and effective, thus requiring an entry of "Y" on Data Record B, card B11, block 5B (Disposition), card column B.

(12) Decision 12. Is lubricate/service applicable and effective? This decision point can be entered from decision point 6 or 11. This will determine whether the lubrication or service will be operator/crew or a higher maintenance level, i.e., organizational or intermediate support. Again, the task must be applicable and effective before "Y" can be entered in decision point 12. If both lubricate and service are applicable and effective, lubricate is preferred over service due to less cost and man-hours required. An "N" indicates that neither lubricate or service is effective or applicable. The appropriate entry will be made on Data Record B, card B11, block 5A, card column 12.

(13) Decision 13. Is inspect/test applicable and effective?

(a) This decision point identifies critical or hidden components where impending failure is detectable. Arrival at this decision point by answering "yes" to decision 6 indicates that the impending failure can only be detected by maintenance. Operate to failure is one choice if scheduling a maintenance action is not applicable and effective. In cases where there is the option of selecting operator/crew or maintenance, operator/crew is preferred when the probability of detection is equal. If analysis reveals a higher detection probability for maintenance, consideration should be given to inclusion of a scheduled task or inspection in the maintenance plan.

(b) Test is preferred over inspect if both are applicable and effective; however, if only one can provide the level of mission/safety requirements, then that task would be selected.

(c) A "yes" decision indicates that the inspect or test task is both applicable and effective. A "no" indicates that neither an inspect or test task is both applicable and effective. The appropriate entry will be made on Data Record B, card B11, block 5A, card column 13.

(14) Decision 14. Is adjust/align/calibrate applicable and effective?

(a) The tasks that are available in this decision point are in preferred sequence. That is, adjust is preferred over align and align over calibrate. It is possible that a single task may not provide the adequate mission/safety requirements and a combination of tasks may be required.

(b) The appropriate entry will be made on Data Record B, card number B11, block 5A, card column 14.

(15) Decision 15. Is replace/overhaul applicable and effective?

(a) This decision point identifies critical or hidden components that exhibit wear-out characteristics where impending failure can be detected. In components that fall into this category, the inherent reliability and safety levels can be preserved by either a restoration or discard task. Each of the two alternatives must be analyzed in terms of cost and the reliability and safety levels that can be maintained under each alternative.

(b) A scheduled replacement may be more cost-effective if a time limit can be established that, with a high degree of confidence, provides the necessary reliability and safety protection levels. In other cases, where the component is costly or there are not enough data to confidently establish a replacement interval, then a scheduled overhaul may be more cost-effective. In each case, the benefits and risks of each alternative maintenance decision should be analyzed to select the most cost-effective task. If both replace and overhaul are considered feasible, then the benefits and risks should justify the selection of the alternative. If the answer to replace/overhaul is "no," continue on to the next decision point. The appropriate entry will be made on Data Record B, card number B11, block 5A, card column 15. Anytime that replace/overhaul is considered, the options of age exploration and redesign must also be considered.

(16) Decision 16. Is age exploration applicable? This decision point addresses age exploration and the identification of critical or hidden failure modes that require monitoring and updating of the maintenance plan. Age exploration must be considered for any failure mode that results in entry into any of blocks 11-15, inclusive. This decision point is used during the initial analysis and for any update of the RCM as data becomes available through test, analysis, and actual field use. If any category 1 or 2 failure mode that is addressed through this logic is found to require continued monitoring or testing after development, and the current maintenance plan does not satisfy the safety and mission requirements, then this decision point will be answered "yes," identifying the item as a candidate for an age exploration effort (see chap 7 for a more detailed discussion of the age exploration program). A "yes" answer to this question requires an entry of "Y" on Data Record B, card number B11, block 5B (Disposition), card column D. Also, the appropriate entry will be made on Data Record B, card number B11, block 5A, card column 16. This disposition must be accompanied by one of the other dispositions. This failure mode will appear on the LSA 50 report, Reliability Centered Maintenance Summary, identifying it as an item for age exploration. Either a "yes" or "no" answer to age exploration will take us to Decision Point 18. See paragraph 4-7.b(18) for further instructions.

(17) Decision 17. Is redesign applicable?

(a) This decision point allows the analyst to review the maintenance program for each failure to ensure that it will meet the required mission and safety levels. A task analysis will be performed to select the best task or combination of tasks that will meet these requirements. If this analysis indicates that the maintenance tasks will not meet the requirements, redesign should be considered. The cost and feasibility of a redesign must be considered along with the potential benefits derived from the redesign. In some cases, the required redesign may involve the addition of a test point or measurement device, while, in others, the cost of redesign may be prohibitive or the incorporation of a redesign may not be technically feasible.

(b) When a decision has been made that redesign is a viable alternative, an entry of "Y" is required on Data Record B, card number B11, block 5B (Disposition), card column E. Also, the appropriate entry will be made on Data Record B, card number B11, block 5A, card column 17. The LSA 50 report, RCM Summary, will indicate that a design change is being considered, but a decision has not been made as to the extent or type of design change.

(c) Since RCM is a reiterative process as the design matures and data becomes available, the redesign decision point will be used less and less. If redesign is not applicable, reenter logic chart at decision point 1. Evaluate all previous decisions considering that redesign is not applicable and that an alternative solution must be chosen.

(18) Decision 18. Is there a "Y" in card colum 11 through 14 An answer of "yes" to the question asked at this decision point allows termination of the RCM logic process. If a scheduled maintenance task has been identified for the

failure mode being analyzed, the question asked at this decision point will be answered "yes" and the logic process terminates for this iteration. Any subsequent iteration(s) will be predicated upon change(s) affecting the decisions made during this analysis. If the question asked at this decision point is answered "no," the remaining decision points (8, 9, 10, and 17) must be considered. The appropriate entry will be made on Data Record B, card number B11, block 5A, card column 18.

4-10. **RCM task selection.** Upon completion of each failure mode through the RCM logic, analysis of preferred task is performed to select the most applicable and effective maintenance task or combination of maintenance tasks that will meet the required mission and safety requirements. The scheduled maintenance tasks selected must meet the criteria of applicability and effectiveness (para 5-8). When this analysis is completed, which will include a determination of interval, enter the task/tasks in card number B11, block 5E on Data Record B, and the time required to complete the scheduled task/tasks in card number B11, block 5F on Data Record B. The entries made in these blocks will be carried over into the C and D data records of the LSAR.

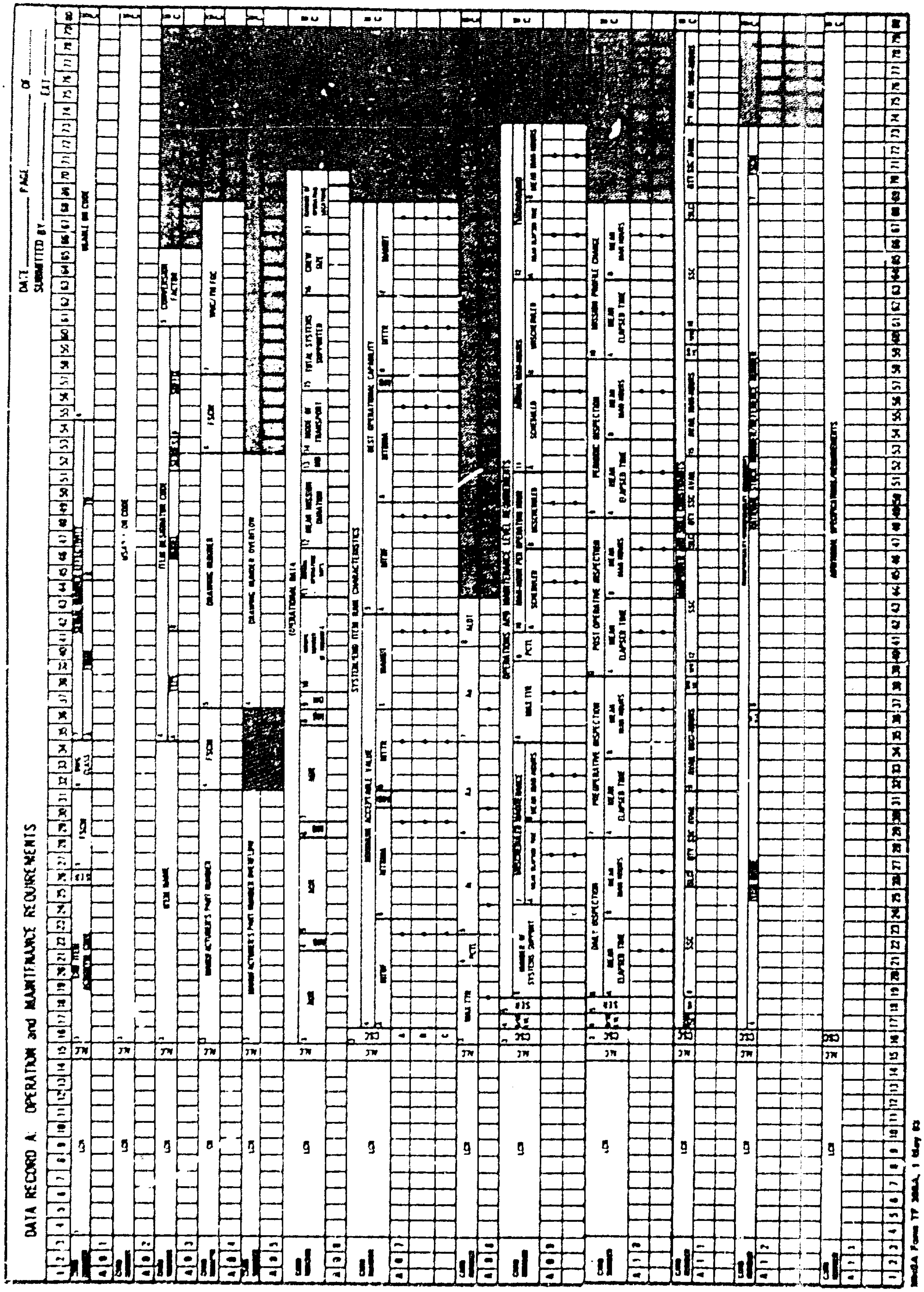

Figure 4-2. LSAR Data Record A

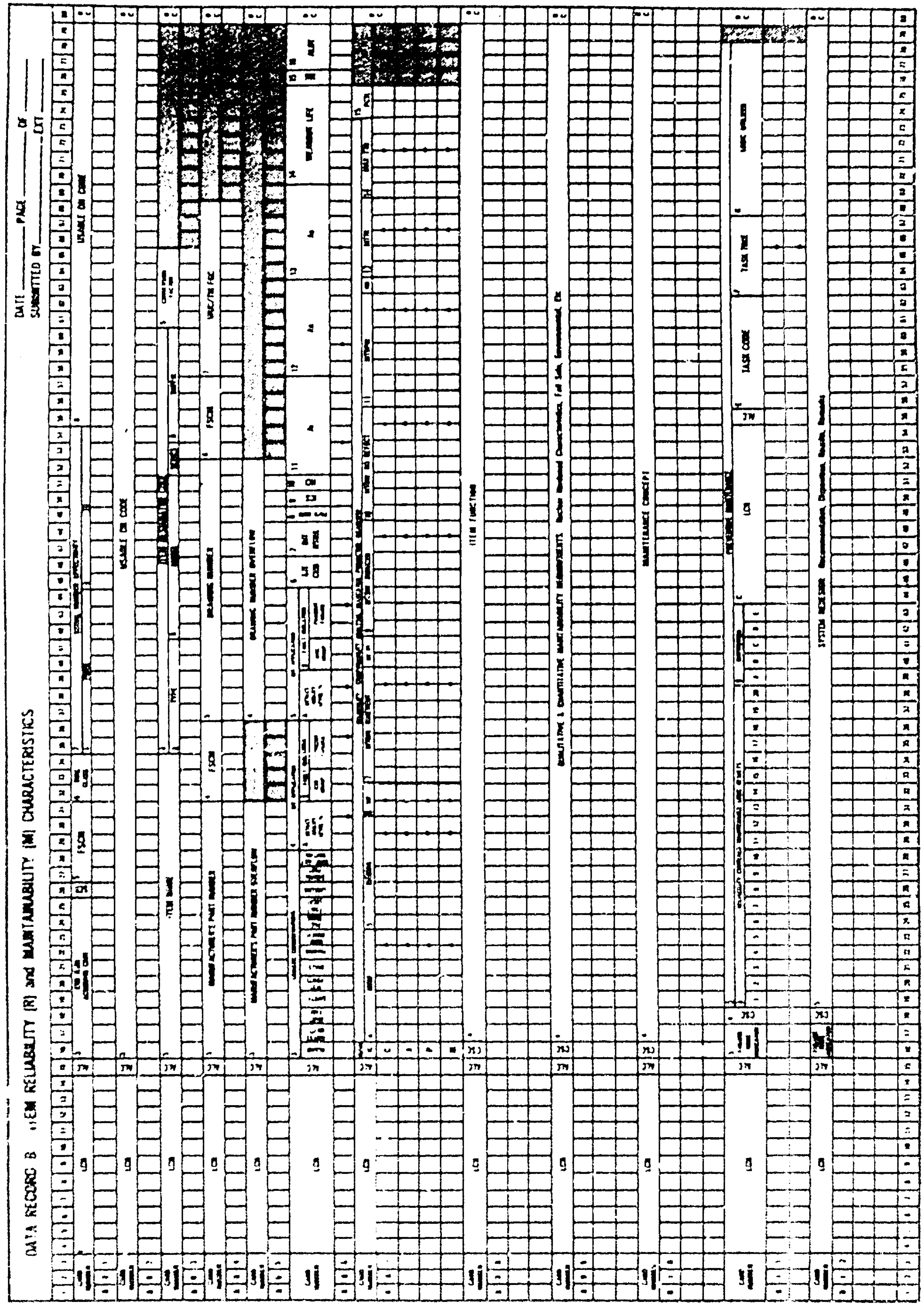

Figure 4-3. LSAR Data Record B

DATA RECORD B1: FAILURE MODES and EFFECTS ANALYSIS

DATE ________ PAGE ________ OF ________
SUBMITTED BY ________ EXT ________

CARD NUMBER | LCN | ALC | FAILURE MODE INDICATOR | CSC | FAILURE MODE CODE | FAILURE MODE AND CAUSE (101)/DAMAGE MODE (104) | FMRN | MISSION PHASE/OPERATIONAL MODE

CARD NUMBER | LCN | ALC | FAILURE MODE INDICATOR | CSC | FAILURE EFFECT CODE | FAILURE/DAMAGE EFFECTS (101)/(104): LOCAL NEXT HIGHER LEVEL END EFFECT

CARD NUMBER | LCN | ALC | FAILURE MODE INDICATOR | CSC | FAILURE DETECT CODE | FAILURE DETECTION METHOD | COMPENSATING PROVISIONS

MRSA Form TF 3548B1, 1 May 83

Figure 4-4. LSAR Data Record B1

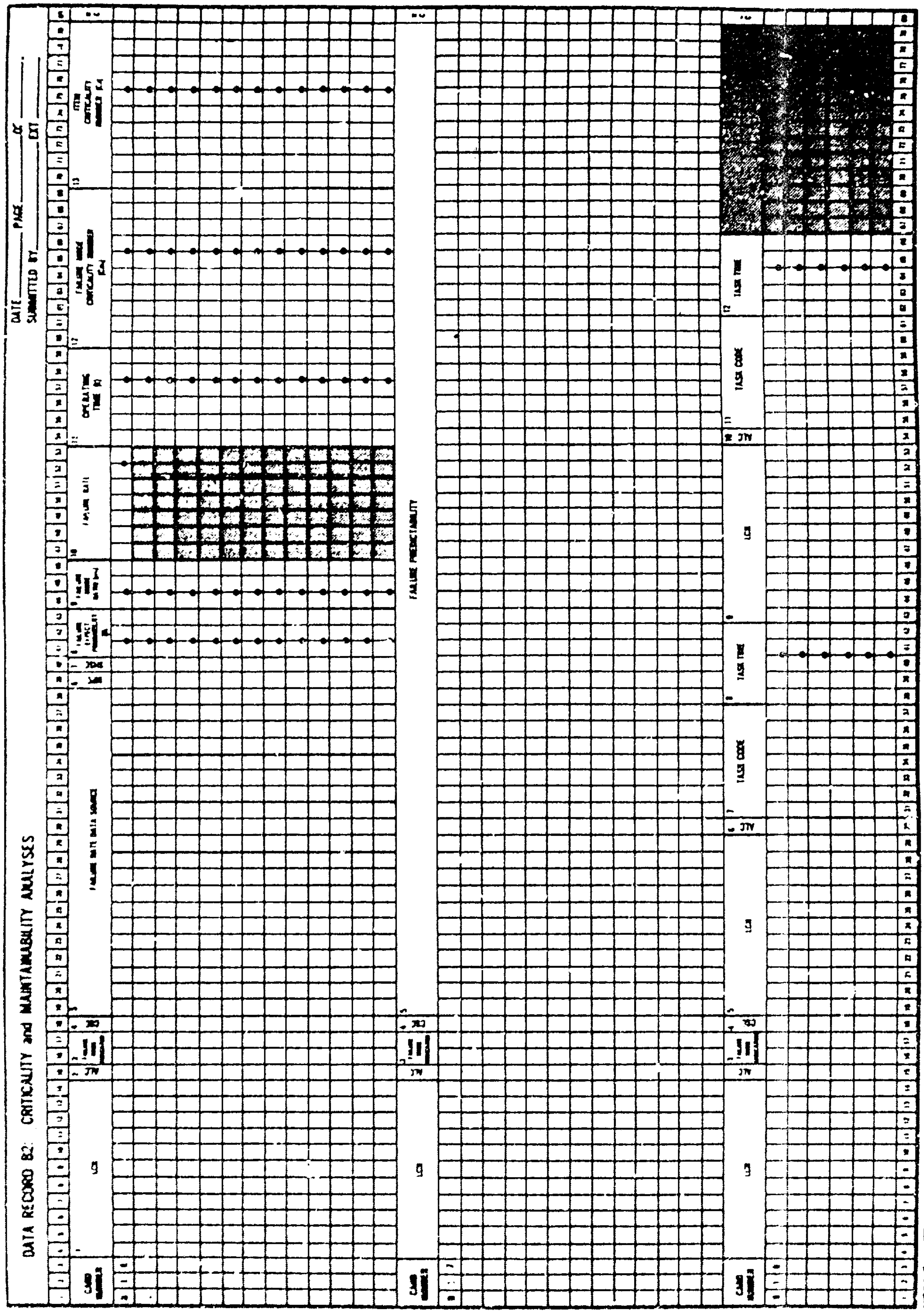

Figure 4-5. LSAR Data Record B2

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RCM LOGIC

*EVERY DECISION MADE BY USING THIS LOGIC DIAGRAM WILL RESULT IN AN ENTRY ON THE B SHEET LSAR DATA RECORD ON THE B11 CARD IN SUBCOLUMN 5A, BLOCKS 1-18 (19-20 ARE SPARES). ADDITIONAL ENTRIES MAY BE REQUIRED. SEE PARAGRAPH 4-9 FOR DETAILED INSTRUCTIONS.

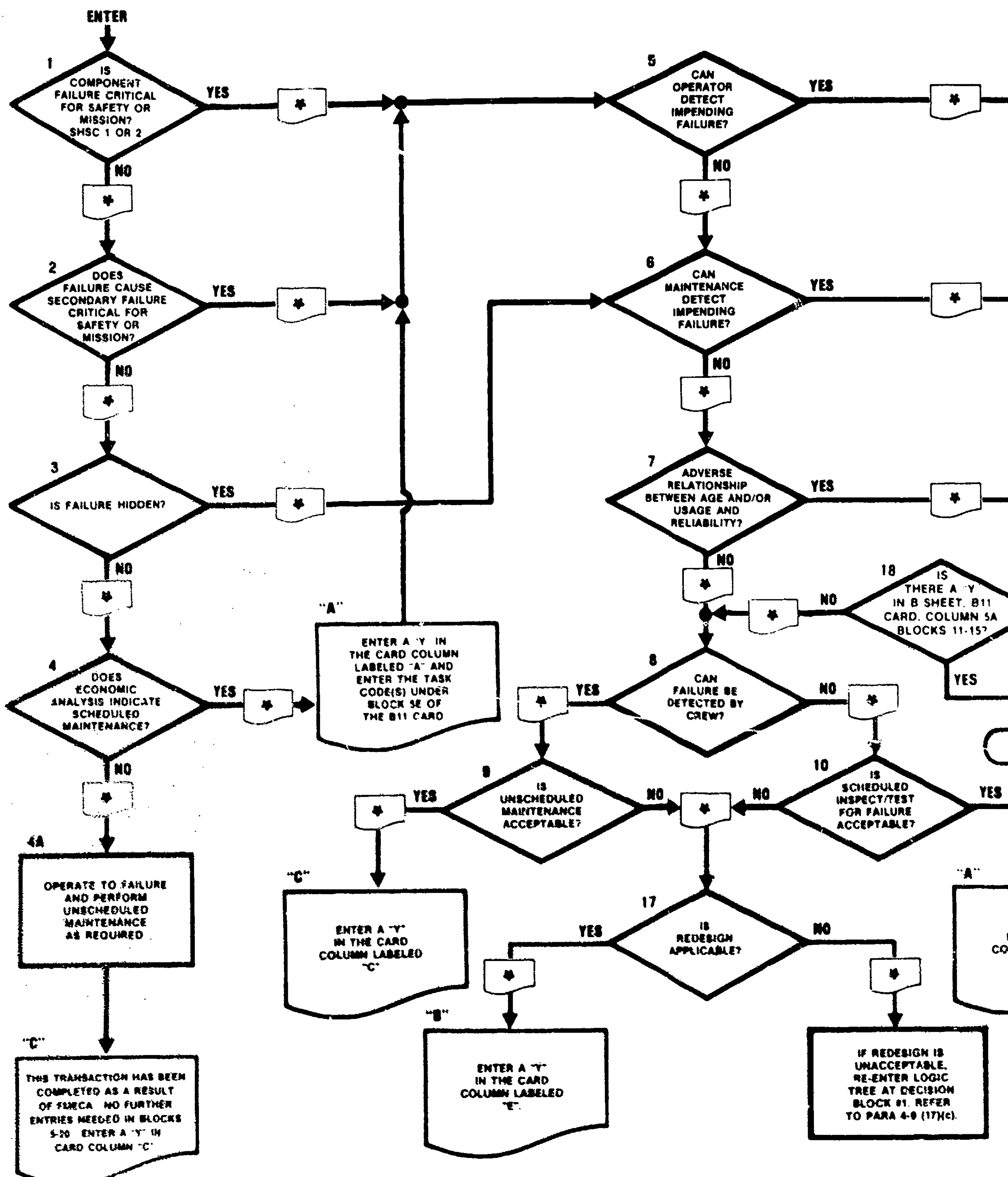
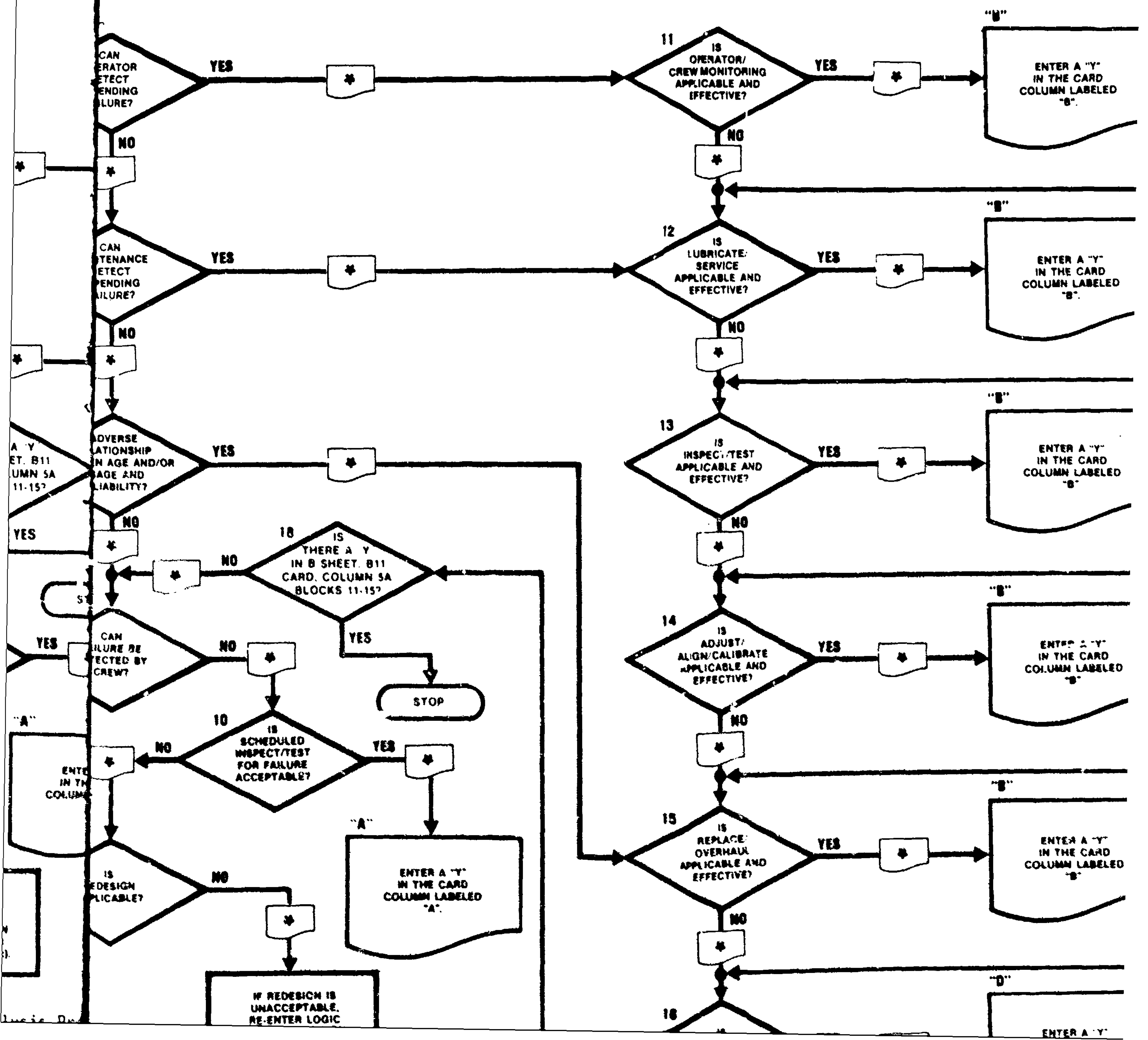


Figure 4-6. RCM Analysis

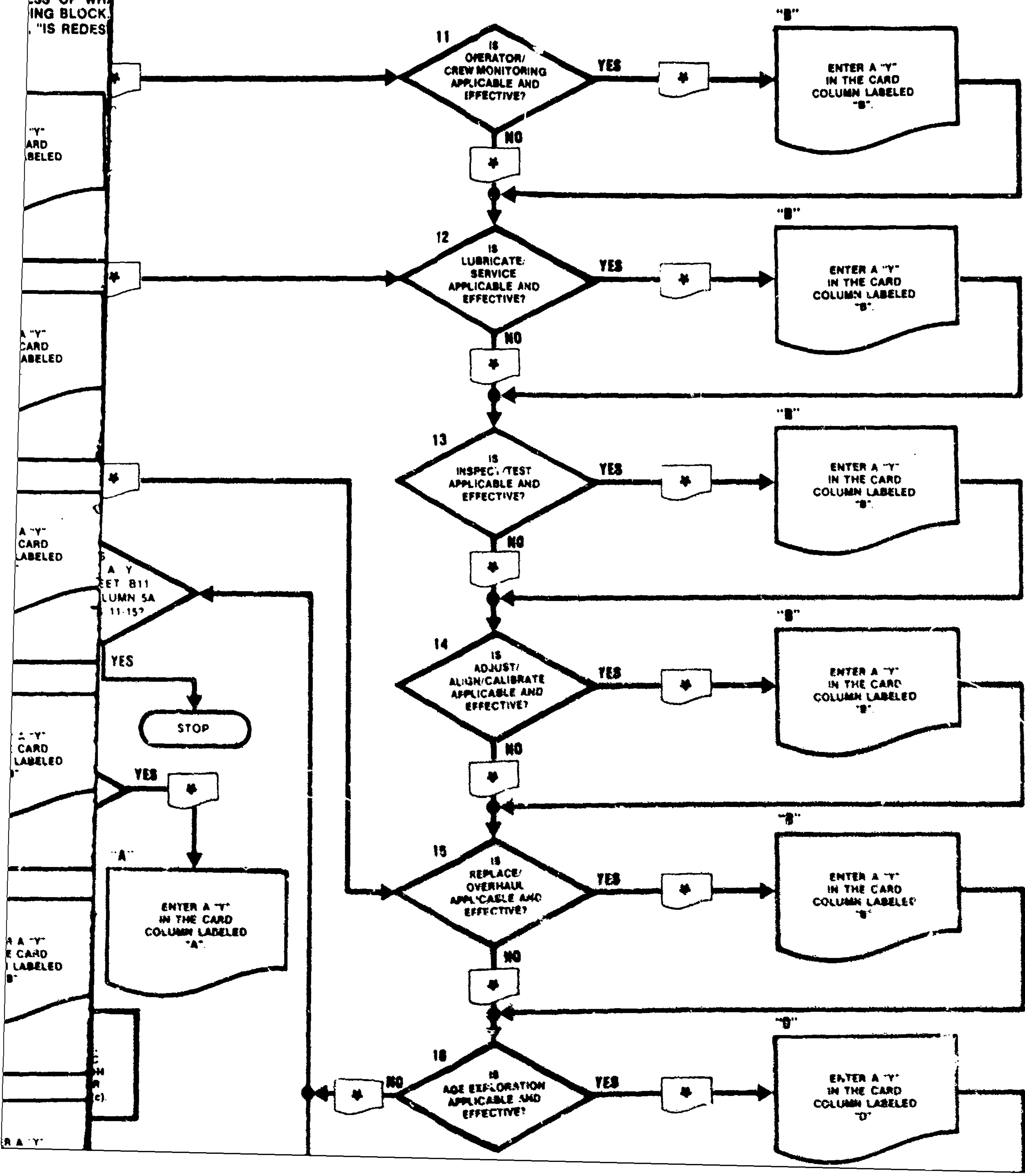
RCM LOGIC

NOTE: AFTER ENTERING BLOCKS 11-15, ALL REMAINING BLOCKS OF THAT SEQUE BE CONSIDERED REGARDLESS OF DECISION IS IN ANY PRECEDING BLO MAY TAKE US TO BLOCK 17. "IS RED APPLICABLE?"



GIC

NOTE: AFTER ENTERING BLOCKS 11-15, ALL REMAINING BLOCKS OF THAT SEQUENCE MUST BE CONSIDERED REGARDLESS OF WHAT THE DECISION IS IN ANY PRECEDING BLOCK. THIS MAY TAKE US TO BLOCK 17, "IS REDESIGN APPLICABLE?"



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CHAPTER 5

MAINTENANCE APPLICATION

5-1. General. The determination of any required scheduled maintenance is developed from the RCM logic and the effect of degradation/failure to the item, based on the impact to safety, mission, and economics.

5-2. Safety and mission consideration.

a. Safety.

(1) Safety consideration must be classified as SHSC catastrophic (category 1) or critical (category 2) for any failure that could have a direct effect on safety The impact of the failure must be immediate and the adverse effect must be one that will be felt before planned completion of a mission. If a failure has no evident results, it cannot, by definition, have a direct effect on safety. Safety consequences will be assessed at the most conservative level, and in the absence of proof that a failure cannot affect safety, it is classified by default as critical. However, as long as the failure has no immediate safety consequences, the need for precautionary measures does not justify classifying the failure as critical.

(2) For every catastrophic or critical failure identified, every attempt will be made to prevent the occurrence. Often, redesign of one or more vulnerable items is necessary. However, the design and manufacture of new parts and their subsequent incorporation in the equipment takes a considerable amount of time. Hence, other action is required during the interim. In the case of turbine-blade failure, an identifiable direct adverse effect, it has been found that blades will loosen well in advance of actual separation. Thus, a scheduled inspection for this condition makes it possible to remove engines at the potential-failure stage, thereby, forestalling the critical functional failure.

Note: This preventive maintenance task does not prevent failure; rather, by substituting a potential failure for a functional failure, it precludes the consequences of a functional failure.

b. Mission capable/readiness.

(1) Whenever the need to correct a failure disrupts planned missions, the failure has operational consequences. Thus, unscheduled maintenance which requires the delay or cancellation of the mission is classified as critical (category 2) for mission capability.

(2) A failure that requires immediate correction does not necessarily have mission capable consequences. For example, if a failed item can be replaced/repaired without delay or cancellation of a mission, then it should be classified less than category 2 (critical).

(3) Every effort will be made to prevent the occurrence of catastrophic or critical failures through redesign or preventive maintenance.

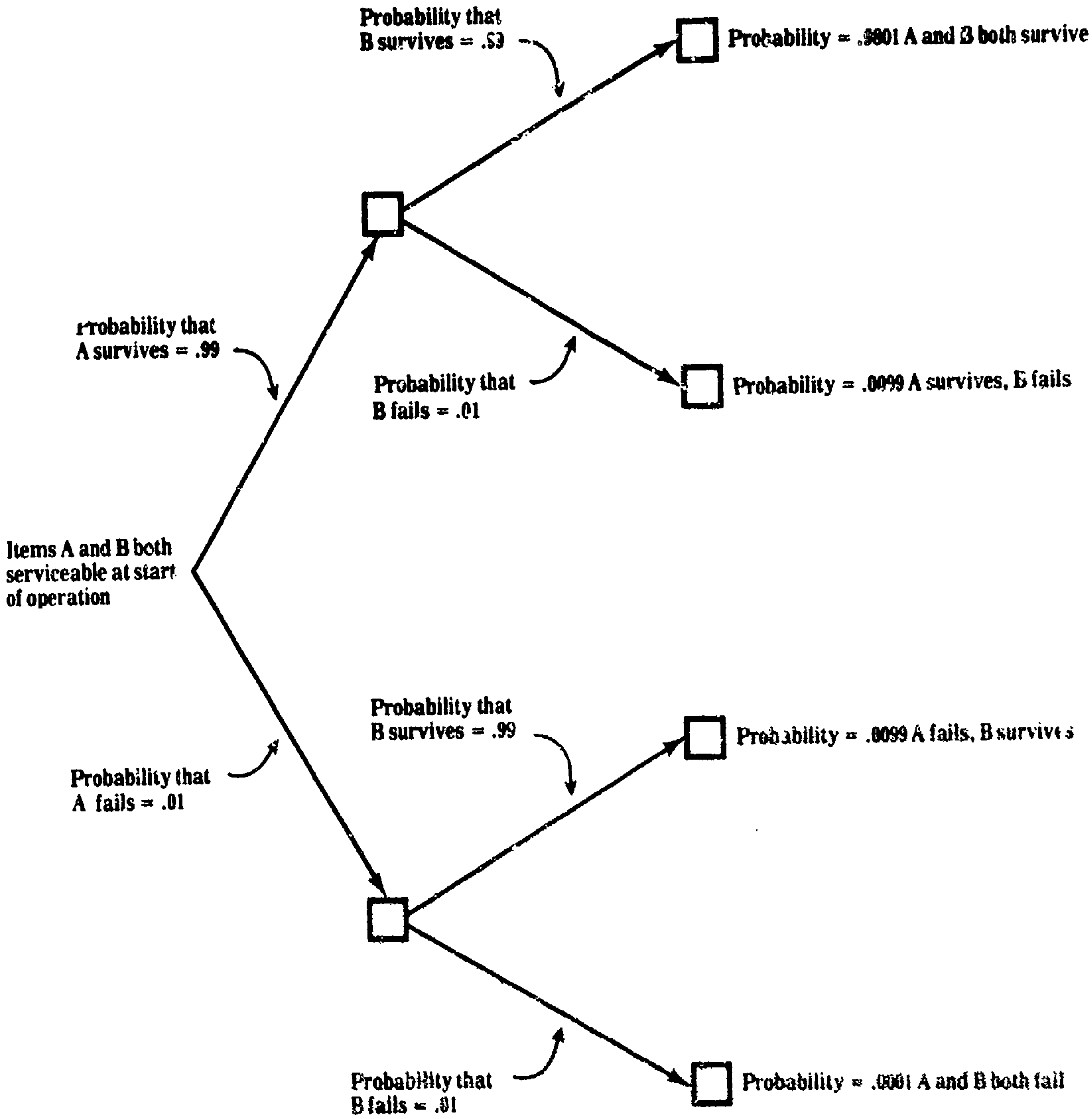
5-3. Hidden failure considerations. Hidden failures are an important class of failures that have no immediate/direct adverse effect on use of the function. However, the ultimate consequence can be critical if a hidden failure is not detected and corrected; e.g., unusual mission events could require the failed function. Therefore, the consideration of any hidden-function failure is increased exposure to the consequence of multiple failure.

5-4. Multiple failures. Failure consequences are often assessed in terms of a sequence of independent events leading to a multiple failure, since several successive failures may result in consequences that no single failure would produce individually. The probability of a multiple failure is simple to calculate. Suppose items A and B in figure 5-1 both have a probability of 0.99 of surviving a given 2-hour flight (this would correspond to one failure per 100 flights, which is, in fact, a very high failure rate). If items A and B are both functioning at takeoff time, there are only four possible outcomes--

- Item A survives and item B survives: P = 0.99 x 0.99 = 0.9801.
- Item A survives and item B fails: P = 0.99 x 0.01 = 0.0099
- Item A fails and item B survives: P = 0.01 x 0.99 = 0.0099
- Item A fails and item B fails: P = 0.01 x 0.01 = 0.0001

In other words, the probability that A and B will both fail during the mission is only 0.0001, or an average of once in 10,000 missions. If we were considering a multiple failure of three items, the average occurrence, even with the high failure rate we have assumed here, would be once every million missions. Note the difference, however, if item A is in a failed state when the mission begins. The probability that B will fail is .01; thus, the probability of a multiple failure of A and B depends only on the probability of the second failure .01, or an average of one occurrence every 100 missions. This becomes a matter of concern if the combination has critical consequences. Because of the increased probability of a multiple failure, hidden-function items are placed in a special category, and all such items that are not subject to other maintenance tasks are scheduled for failure-finding tasks. Although this type of task is intended to discover hidden failures, rather than to prevent, it can be viewed as preventive maintenance because one of its objectives is to reduce exposure to a possible multiple failure.

a. To illustrate how the consequences of a multiple failure might be evaluated, consider a sequence of failures, all of which are evident. If the first failure has safety consequences, there is no need to assess the consequences of a second failure. This first critical failure is the sole concern, and every effort is made to prevent its occurrence. When the first loss



Tree diagram showing the probability of a multiple failure of two items during the same mission when both items are serviceable at initial startup.

Figure 5-1. Multiple Failures

of function is not critical, then the consequences of a second loss of function must be investigated. If the combined effect of both failures would jeopardize safety, then this multiple failure must be prevented by correcting the first failure as soon as possible. This may entail an unscheduled landing and will at least require taking the equipment out of service until the condition has been repaired. In this case, therefore, the first failure has operational consequences.

b. Note in figure 5-2 that the multiple-failure consequences need be assessed only in terms of two successive failure events. If a third loss of function would be critical, the second failure has operational consequences. However, the first failure in such a sequence can be deferred to a convenient time and place; thus, it has no operational consequences. Hidden-function failures are assessed on the same basis. If the first failure under consideration is a hidden one, scheduled maintenance is necessary to protect against a multiple failure. The intensity of this maintenance, however, is dictated by the consequences of the possible multiple failure. If the combination of this failure with a second failure would be critical, every effort is made to ensure that the hidden-function will be available.

c. Treating any single failure as the first in a succession of events that could lead to a critical multiple failure, permits the analyst to base a maintenance program on the consequences of single failures.

5-5. Failure in complex items.

a. A complex item is one that is subject to many different failure modes. As a result, the failure processes may involve a dozen different stress and resistance considerations, and a correspondingly tangled graphic representation. However, each of these considerations pertains to a single failure mode - some particular type or manner of failure. For instance, a bearing in a generator may wear, causing the unit to vibrate and, ultimately, the bearing will seize. At this point the generator will suffer a functional failure, since it can no longer rotate and produce electric power. Generators can also fail for other reasons, but the failure mode in this case is bearing seizure. Of course, the bearing itself is also subject to more than one failure mode. It may wear as a result of abrasion or crack as a result of excessive heat. From the standpoint of the generator, both conditions lead to the same failure, bearing seizure; however, the maintenance analyst must know the physical circumstances leading to a particular failure in order to define an identifiable potential-failure condition. The manufacturer also needs to know that the bearing is prone to failure, and that a modification is needed to improve the reliability of the generator. Such a design modification is obviously desirable if one particular failure mode is responsible for a significant proportion of all the failures of the item. Such failure modes are called dominant failure modes.

b. As with failures in simple items, the failure ages for a single failure mode tend to concentrate about an average age for that mode. However, the average ages for all the different modes will be distributed along the exposure axis.

Nature of Failure Consequences				
First failure	Second failure	Third failure	Fourth failure	Effect on previous failures in sequence
Critical				The critical nature of the first failure supersedes the consequences of a possible second failure.
Operational	Critical			A second failure would be critical; the first failure must be corrected before further dispatch and, therefore, has operational consequences.
Nonoperational	Operational	Critical		A third failure would be critical; the second failure must be corrected before further dispatch, but correction of the first failure can be deferred to a convenient time and location.
Nonoperational	Nonoperational	Operational	Critical	A fourth failure would be critical; the third failure must be corrected before further dispatch, but correction of the both the first and second failures can be deferred.

The consequences of a single failure as determined by the consequences of a possible multiple failure. A failure that does not, in itself, affect operating capability, acquires operational consequences if a subsequent multiple failure would be critical.

Figure 5-2. Multiple-Failure Consequences

Consequently, unless there is a dominant failure mode, the overall failure ages in complex items are usually widely dispersed and are unrelated to a specific operating age. This is a unique characteristic of complex items. Nevertheless, even in complex items, no matter how numerous the failure modes may be, the basic failure process reduces to the same factor, the interaction between stress and resistance to failure. Whether failures involve reduced resistance, random stress peaks, or any combination of the two; it is this interaction that brings an item to the failure point. The end item as a whole, its basic structure, its systems, and the various items in it are operated in an environment which causes stresses to be imposed upon them. The magnitudes, the durations and the frequencies with which specific stresses are imposed are all variable. In many cases, the real spectrum of environmentally produced stresses is not known. The ability to withstand stress is also variable. It differs from piece to piece of new nominally identical equipment due to material differences, variations in the manufacturing processes, etc. The ability to withstand stress may also vary with the age of a piece of equipment. It is implied that an instance of environmental stress that exceeds the failure resistance of an item at a particular time constitutes failure of that item at that time.

5-6. Quantitative description of failure. Any unanticipated catastrophic or critical failure prompts an immediate response to prevent the reoccurrence. In other cases, however, it is necessary to know how frequently an item is likely to fail in order to plan for reliable operation and safety. There are several common reliability indexes on the failure history of an item.

a. Failure rate.

(1) The failure rate is the total number of failures divided by some measure of operational exposure. In most cases the failure rate is expressed as failures per 1,000,000 or 10^{-6} operating hours. Thus, if six failures have occurred over a period of 9,000 hours, the failure rate is ordinarily expressed as 0.667×10^{-3} failure/operating hour or 667×10^{-6} failures/operating hours. Because measures other than operating hours are also used (flight cycles, calendar time, etc.), it is important to know the units of measure in comparing failure rate data.

(2) The failure rate is an especially valuable index for new equipment, since it shows whether the failure experience of an item is representative of the state-of-the-art. It is also useful in assessing the economic desirability of product improvement. Early product improvement decisions are based on the performance of units that have been exposed to fairly short individual periods of time in service, and this performance is adequately measured by the failure rate.

b. Mean time between failures (MTBF). The MTBF, another widely used reliability index, is the reciprocal of the failure rate. Thus, for six failures in 9,000 operating hours, the MTBF would be 9,000/6, or 1,500 hours. This measure has the same uses as the failure rate. Note that the MTBF is not necessarily the same as the average age at failure.

c. Probability of survival.

(1) With more extended operating experience, it becomes possible to determine the age-reliability characteristics of the item under study--the relationship between its operating age and its probability of failure. At this stage, we can plot a survival curve, showing the probability of survival without failure as a function of operating age. This curve relates directly to the generally accepted definition of reliability. For this reason, the survival curve is commonly referred to as the reliability function.

(2) A survival curve is more useful than a simple statement of the failure rate, since it can be used to predict the percentage of units that will survive to some given age. The area under the survival curve can also be used to measure the average life of the item under consideration. If the probability scale is divided into small increments, each of which is projected to intersect the curve, the contribution of each of these incremental areas can be calculated and added to determine the average life.

d. Probability of failure. Assuming the probability that an engine will survive to 1,000 hours is .692, and the probability that it will survive to 1,200 hours is .639. The difference between these probabilities, .053, is the probability of a failure during this 200-hour interval. In other words, an average of 5.3 out of every 100 engines that enter service can be expected to fail during this particular interval. Similarly, an average of 5.0 engines can be expected to fail during the interval from 1,200 to 1,400 hours. This measure is called the probability density of failure.

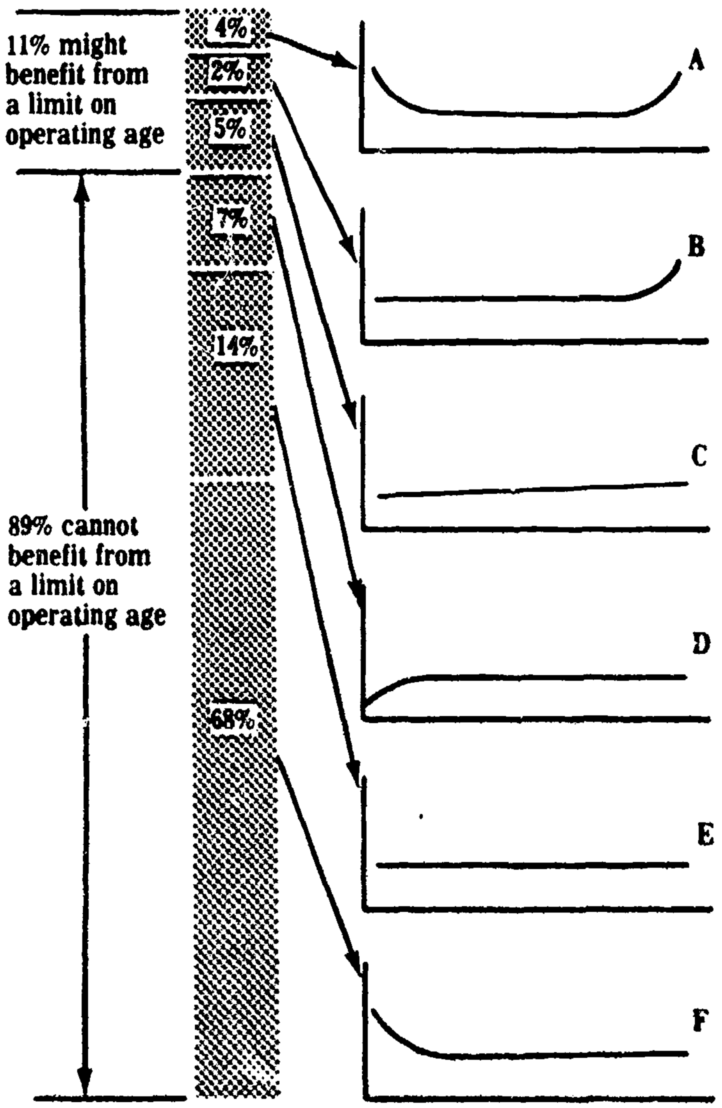
e. Conditional probability of failure.

(1) The most useful measure of the age-reliability relationship is the probability that an item entering a given age interval will fail during that interval. This measure is usually called the conditional probability of failure, i.e., the probability of failure, given the condition that the item enters that age interval. Sometimes, it is also referred to as the hazard rate or the local failure rate.* The conditional probability is related to both the probability of survival and the probability density. For example, an engine beginning at zero time has a probability of .692 of reaching the age of 1,000 hours; once it has reached this age, the probability density of failure in the next 200-hour interval is .0053. Each engine that survives to 1,000 hours, therefore, has a conditional probability of failure between 1,000 and 1,200 of $^{.053}/_{.692}$, or .077.

(2) If the conditional probability of failure increases with age, we say that the item shows wearout characteristics and immediately wonder if an age limit would be effective in reducing the overall failure rate. (Note that the term wearout in this context describes the adverse effect of age on reliability; it does not necessarily imply any evident physical change in individual units.)

* In some literature these terms are defined in a narrower sense to mean the value obtained by computing the limit of the ratio as the age interval goes to zero.

Age-reliability patterns. In each case the vertical axis represents the conditional probability of failure and the horizontal axis represents operating age since manufacture, overhaul, or repair. These six curves are derived from reliability analyses conducted over a number of years, during which all the items analyzed were found to be characterized by one or another of the age-reliability relationships shown. The percentages indicate the percentage of items studied that fell into each of the basic patterns (United Airlines)



The bathtub curve: infant mortality, followed first by a constant or gradually increasing failure probability and then by a pronounced "wearout" region. An age limit may be desirable, provided a large number of units survive to the age at which wearout begins.

Constant or gradually increasing failure probability, followed by a pronounced wearout region. Once again, an age limit may be desirable (this curve is characteristic of aircraft reciprocating engines).

Gradually increasing failure probability, but with no identifiable wearout age. It is usually not desirable to impose an age limit in such cases (this curve is characteristic of aircraft turbine engines).

Low failure probability when the item is new or just out of the shop, followed by a quick increase to a constant level.

Constant probability of failure at all ages (exponential survival distribution).

Infant mortality, followed by a constant or very slowly increasing failure probability, (particularly applicable to electronic equipment).

Figure 5-3. Age-Reliability Characteristics

5-7. Age-reliability characteristics.

a. At one time, it was believed that all equipment would show wearout characteristics, and during the years when equipment overhaul times were being rapidly extended, the numerous conditional-probability curves for aircraft components were developed to ensure that the higher overhaul times were not reducing overall reliability. It was found that the conditional-probability curves fell into the six basic patterns shown in figure 5-3. Pattern A is often referred to in reliability literature as the bathtub curve. This type of curve has three identifiable regions--

(1) An infant-mortality region, the period immediately after manufacture or overhaul in which there is a relatively high probability of failure.

(2) A region of constant and relatively low failure probability.

(3) A wearout region, in which the probability of failure begins to increase rapidly with age.

b. If the failure pattern of an item does, in fact, fit this curve, we are justified in concluding that the overall failure rate will be reduced if some action is taken just before this item enters the wearout zone. In these cases, allowing the item to age well into the wearout region would cause an appreciable increase in the failure rate. Note, however, that such action will not have much effect on the overall rate unless there is a high probability that the item will survive to the age at which wearout appears.

c. The presence of a well defined wearout region is far from universal. Indeed, of the six curves in figure 5-3, only A and B show wearout characteristics. It happens, however, that these curves are associated with a great many single-celled or simple items. In the case of aircraft, such items as tires, reciprocating-engine cylinders, brake pads, turbine-engine compressor blades, and all parts of the airplane structure.

d. Most complex items had conditional-probability curves represented by curves C to F--that is; they showed no concentration of failures directly related to operating age.

e. The basic difference between the failure patterns of complex and simple items has important implications for maintenance. Usually the conditional-probability curve for a complex item will show some infant mortality; often the probability of failure right after installation is fairly high. Also, the conditional-probability curve usually shows no marked point of increase with increasing age; the failure probability may increase gradually or remain constant, but there is no age that can be identified as the beginning of a wearout zone. For this reason, unless there is a dominant failure mode, imposing an age limit does little or nothing to improve the overall reliability of a complex item. In fact, in many cases, scheduled overhaul actually increases the overall failure rate by introducing a high infant-mortality rate in an otherwise stable system.

f. In contrast, single-celled and simple items frequently do show a direct relationship between reliability and increasing age. This is particularly true of parts subject to metal fatigue or mechanical wear and items designed as consumables. In this case, an age limit based on some maximum operating age or number of stress cycles may be highly effective in improving the overall reliability of a complex item. Such limits, in fact, play a major role in controlling critical-failure modes, since they can be imposed on the part or component in which a given type of failure originates.

g. It is apparent from the discussion thus far, that most statements about our "life" of equipment tell us little about its age-reliability characteristics. For example, the statement that an aircraft engine has a life of 2,000 operating hours might mean any of the following--

(1) No engines fail before reaching 2,000 hours.

(2) No critical engine failures occur before 2,000 hours.

(3) Half the engines fail before 2,000 hours.

(4) The average age of failed engines is 2,000 hours.

(5) The conditional probability of failure is constant below 2,000 hours.

5-8. Applicability and effectiveness criteria. The RCM task evaluation questions require that both the applicability and effectiveness criteria be met if a task is to be acceptable. Figure 5-4 summarizes the applicability and effectiveness criteria for most cases. It is important to understand that the applicability of a task depends on the failure characteristics of an item, and the effectiveness of a task depends on the failure consequences for each case. Therefore, an applicable task must satisfy the requirements of the characteristics of failure. These requirements are different for scheduled maintenance overhaul and remove/replace tasks as shown in figure 5-4. The applicability criteria is dependent solely on the type of task, regardless of failure consequence. Once a task is chosen which is applicable, the effectiveness of that task in preventing the failure consequences must be determined. Note that in figure 5-4 the effectiveness criteria varies by failure consequences. Therefore, each type of task must meet the same effectiveness criteria under the same consequence of failure. The specific applicability criteria will be discussed in detail as the individual tasks are presented.

a. Effectiveness criteria for safety and hidden failure consequences. The evaluation of the effectiveness criterion is the same for each failure consequence, regardless of the type of task. The effectiveness criteria for each failure consequence are discussed separately. For safety consequences, the effectiveness criteria require that the task reduce the risk of critical failure to an acceptable level. To assess the risk of failure, an iterative process must be followed. After a task is proven to be applicable, an initial task interval is assigned. Using this interval, the probability of failure must be low enough to ensure that failures are very unlikely.

FAILURE CONSEQUENCES

TASK	SAFETY	OPERATIONAL	ECONOMIC	HIDDEN FAILURE
Effectiveness All	Must reduce risk of failure to acceptable level.	Must be cost effective; cost of scheduled maintenance must be less than combined cost of loss	Must be cost effective; cost of scheduled maintenance and the reduced service life per item must be less than the cost of repair.	Ensure level of availability to reduce risk of multiple failure to acceptable level.
Applicability Scheduled Maintenance Task	1. Possible to detect reduced failure resistance. 2. Possible to define potential failure condition that can be detected by an explicit task. 3. Consistent age between potential failure and functional failure.	Same	Same	Same
Overhaul	1. Identify age with rapid increase in conditional probability of failure. 2. Large percentage must survive to this age. 3. Possible to restore original failure resistance by rework.	Same	Same	Same
Scheduled Remove/ Replace	1. Must be critical failure. 2. Specified age limit below which the probability of failure is acceptable.	1. Failure has major operational consequences. 2. Identify age with rapid increase in conditional 3. Large portion must survive to this age	Same as operational	1. Must be critical multiple failure. 2. Specified age limit below which no failure occurs.
Failure Finding Task				1. Must be a hidden function. 2. No other task is applicable or effective.

Figure 5-4. Applicability and effectiveness criteria summary.

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b. Effectiveness criteria for operational and economic consequences. For both operational and economic consequence branches of the decision diagram, the criteria for effectiveness are a cost related matter. For operational consequences, a task may be effective if its cost is less than the combined costs of the loss of operation and the failures that the task prevents. The decision diagram in figure 5-5 can be used to help determine cost-effectiveness. To assess cost of the preventive tasks against the cost of failure, it is necessary to know the failure rate. In question one of figure 5-5, the decision is made whether the failure rate is high. A high rate of failure may be interpreted as different values for different types of equipment. For example, it may be a failure mode which contributes to the majority of failures of an item. Question two involves operational capability. Question three considers high repair or operating costs caused by the failure mode. As shown by figure 5-5, the question is only asked if either of the first two questions are answered "no." Therefore, if the answer to the third question is "no." the cost of a preventive task will be higher than the cost of repair. and the task is not effective. Question four concerns real and applicable data. If the answer to question two or three is "yes," question four is asked. Real and applicable data are operating or other real world data which can be directly applied to the case in question. If this data shows that, for a similar item, a like task proved cost-effective, then the task under evaluation is assumed to be cost-effective for this failure mode. If the answer to question four is "no," then an economic trade-off study is performed. First, consider the purely economic case. The complete cost of the proposed preventive task must be evaluated against the repair cost of the failures the task would prevent. The cost of a preventive task is a function of the interval, man-hours required, and the labor cost for the specified level of maintenance. However, the cost of a corrective task is a function of the failure rate, man-hours required, and the cost of labor at designated levels of repair. For most applications, you can assume that other costs, such as supply support and support equipment are the same for both the preventive and corrective tasks, this relationship could be presented as follows--

C_{pm} = (NT per yr) (DMMH per preventive task) (labor cost per hr)

Where C_{pm} = Cost of preventive task per year

NT = Number of proposed preventive tasks

DMMH = The total number of accumulated direct labor hours expended in performing a maintenance action.

C_{cm} = (NF) (DMMH per corrective task) (labor cost per hr)

Where NF = Number of failures prevented by proposed task per year then

C_{cm} = Cost of prevented failures per year

A cost-benefit ratio can be developed as follows--

$$\text{Cost-benefit ratio} = CBR = \frac{C_{pm}}{C_{cm}}$$

and when the CBR is calculated to be less than one, then the preventive task is considered effective.

When the cost of supply support and supply equipment is not the same for corrective and preventive maintenance, then the relationship can be expressed as follows--

Csepm = Cost support equipment for preventive maintenance.

Csspm = Cost supply support for preventive maintenance.

Csecm = Cost support equipment for corrective maintenance.

Csscm = Cost supply support for corrective maintenance.

CSR = Cost support ratio.

$$CSR = \frac{C_{sepm} + C_{sspm}}{C_{secm} + C_{sscm}}$$

A cost-benefit ratio can then be developed as follows:

$$CBR = \frac{C_{pm}}{C_{cm}} \cdot CSR$$

When the CBR is calculated to be less than 1, then the preventive task is considered effective.

In the case of operational consequences, a similar relationship can be developed--

$$C_{opc} = C_{op} + C_{cm}$$

Where,

C_{opc} = Cost of operational consequences per year and cost of prevented failures per year.

C_{op} = Cost of lost operational time per year.

C_{cm} is defined, above, for purely economic consequences. To define C_{op}, one method can be used as follows--

C_{op} = (Number operational hours lost per failure) (NF) (C_{OH})

Where C_{OH} = Cost of an operating hour

$$C_{OH} = \frac{\text{Acquisition cost of aircraft or equipment}}{\text{Planned operating hours during life cycle}}$$

The final relationship for operational consequences again can be expressed in a cost benefit ratio as follows--

$$CBR = \frac{C_{pm}}{C_{opc}} \text{ and}$$

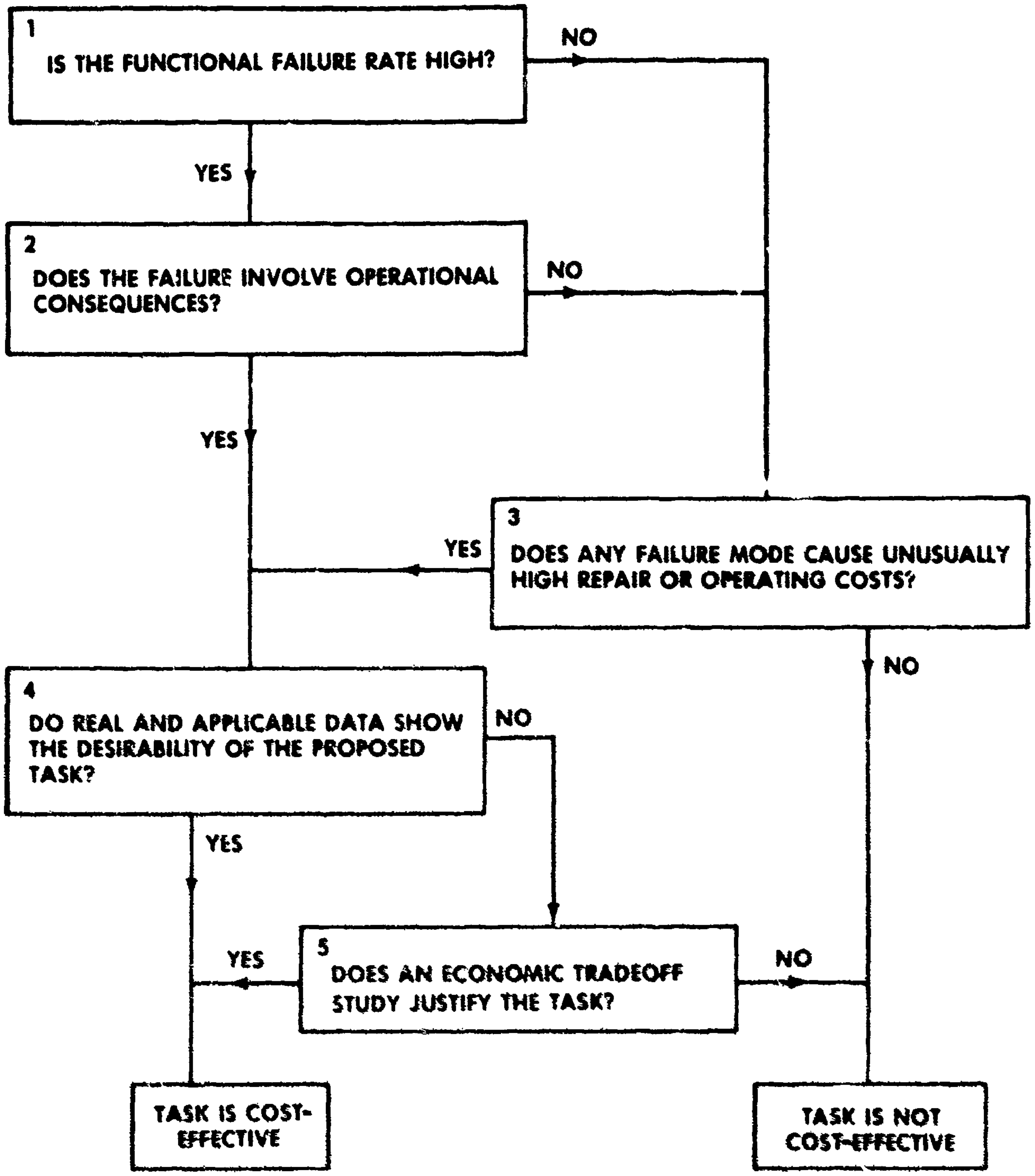
When the ratio is proven to be less than 1, the preventive task is considered cost-effective.

c. Combination of tasks. For safety consequences, a combination of scheduled maintenance, overhaul, or replacement tasks is considered for cases where no individual task is proven applicable and effective. Whenever combinations must be evaluated, it is necessary to reexamine each RCM task for that failure mode, and consider if it can be made applicable and effective in combination with another RCM task. For example, a scheduled maintenance task in combination with a safe life limit may be effective, where neither task was effective alone. The combination of tasks is considered to include every possibility in developing a preventive task or tasks for safety consequences, because the only alternative is to redesign if a preventive task is not found. If an effective and applicable combination task is not developed, redesign is required. If redesign is required by the logic diagram, questions may arise concerning the incorporation of the design change, or whether the item can be safely operated prior to redesign. In these cases concerning safety, conflicts will be resolved by the AMC Safety Office.

d. Scheduled maintenance task evaluation. Scheduled maintenance tasks are the first to be evaluated for applicability and effectiveness. The applicability and effectiveness must be evaluated for each failure mode and failure consequence.

e. Scheduled maintenance. Scheduled maintenance interval and tasks are discussed in chapter 6, but, to identify the applicability, there are three considerations which must be covered. For a scheduled maintenance task to be applicable, the three conditions are--

(1) It must be possible to detect reduced failure resistance for a specified failure mode.



DECISION DIAGRAM FOR EVALUATING THE PROBABLE COST-EFFECTIVENESS OF A PROPOSED TASK WHEN PREVENTIVE MAINTENANCE IS NOT REQUIRED TO PROTECT OPERATING SAFETY OR THE AVAILABILITY OF HIDDEN FUNCTIONS. THE PURPOSE OF THE DECISION TECHNIQUES IS TO REDUCE THE NUMBER OF FORMAL ECONOMIC TRADEOFF STUDIES THAT MUST BE PERFORMED.

Figure 5-5. Decision diagram for cost-effectiveness

(2) It must be possible to define a potential failure condition that can be detected by an explicit task.

(3) There must be a reasonably consistent age interval between the time of potential failure and the time for functional failure.

As an example, suppose a visible crack is used as a measure of metal fatigue, as shown in figure 5-6. Such an item is most failure resistant when it is new (point A). The resistance drops steadily with increasing age and is already somewhat reduced by the time a crack appears (point B). Thereafter, it is possible to monitor the growth of the crack (condition a) and define a potential failure (point C, condition b) far enough in advance to permit removal of the item before a functional failure occurs (point D). Once a crack has appeared, the failure resistance drops more rapidly; hence, the rate of crack growth in this item must be known in order to establish the interval T (condition c), which will enable the inspection interval to be determined that will effectively monitor the failure mode.

5-9. Economic considerations. The economic considerations are divided into two groups, operational and nonoperational effects.

a. Operational effects. Task(s) is desirable if the cost is less than the combined cost of the operational loss and the cost of repair. If economic penalties are severe, redesign may be desirable.

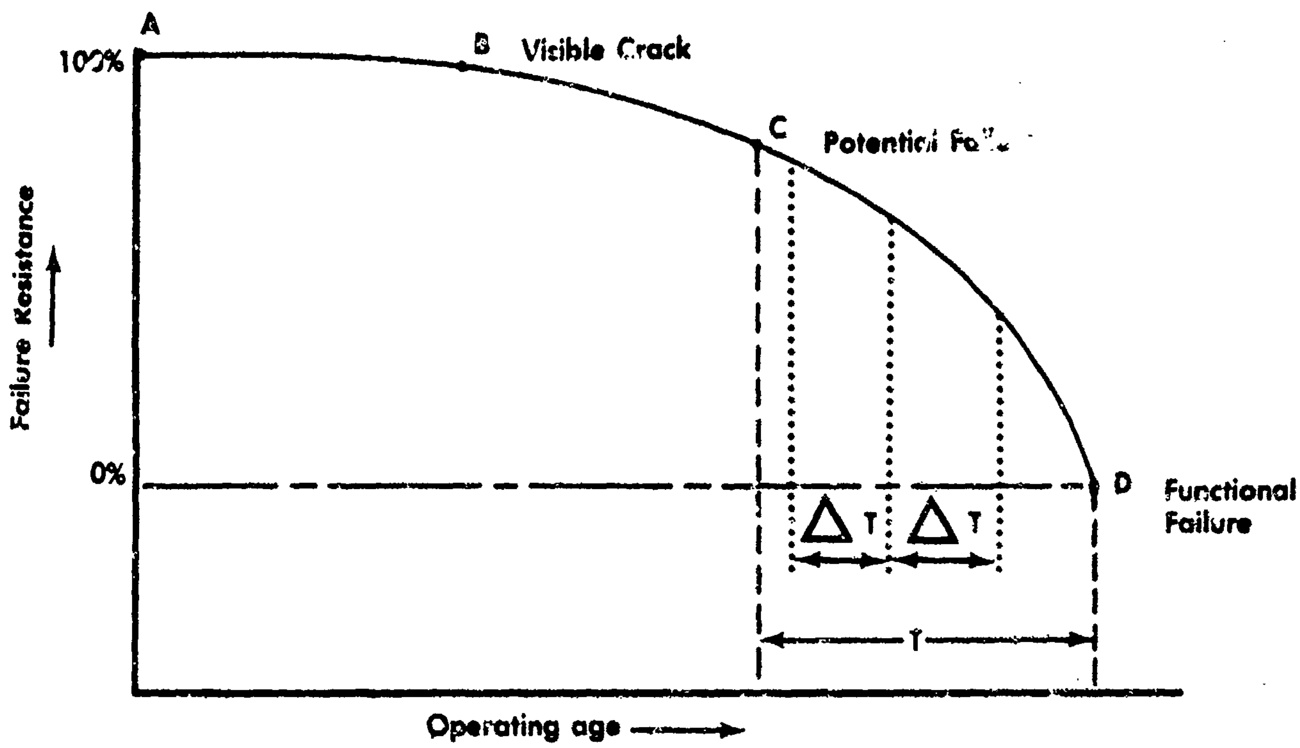
b. Nonoperational effects. Task(s) is desirable if the cost of the task is less than the cost of repair. Redesign may be desirable if economic penalties are severe.

5-10. Determining cost-effectiveness.

a. Since a moderate amount of information gathering is necessary for calculations of cost-effectiveness, it is helpful to know whether the effort is likely to be fruitful. The decision-diagram approach (fig 5-5) is also useful in this area.

b. Up to this point, we have not been concerned about failure rate, since it is not a primary measure of consequences. In the case of critical failures, it has no bearing; in fact, the sole objective is to avoid any failures on which to base a rate. Where the consequences are economic, however, the total cost depends on the frequency with which these consequences are likely to occur. The first question in evaluating the cost-effectiveness of prevention, therefore, concerns the frequency of functional failures.

c. Since it is seldom worthwhile to deal with rare types of noncritical failures, this question rules out items that fail so seldom that the cost of scheduled maintenance would probably be greater than the benefits to be derived from it. The term high, of course, is open to interpretation. In airline practice, a failure rate greater than 1 per 1,000 hours of flight time is usually considered high, whereas, a rate of less than 0.1 per 1,000 hours is usually not considered important. This question is often easier to answer if the failure



Determining the interval for scheduled inspection of an item subject to metal fatigue. Once the rate of decline in failure resistance has been determined, an inspection interval is established that provides ample opportunity to detect a potential failure before a functional failure can occur.

Figure 5-6. Scheduled maintenance task determination

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rate is described in terms of the number of failures per month. If the failure rate is judged to be high, the next concern is the cost involved. Operational consequences are usually the major costs associated with a high failure rate.

d. Any failure that prevents continued dispatch of the equipment involves operational consequences. However, the extent of the economic loss depends largely on the intended use of the equipment. In a military context, for example, a high cost might be imputed to the dispatch of an airplane with restrictions on its operating performance. If the failure does have operational consequences, the total cost of failure includes the combined cost of these consequences and the cost of repair. Even when operational consequences are not involved, it may be advantageous to forestall a particularly expensive failure mode. This question must be investigated separately, since such failure modes will usually be responsible for only a small fraction of the total number of failures. A "yes" answer to either of the preceding two questions means that we need further information. It is possible to arrive at a "yes" answer to this question if there is substantial evidence that this task was cost-effective in the past for this or a similar item. If so, the task can be scheduled without a formal study. Otherwise the question of economic trade-off must be evaluated for each of the applicable maintenance tasks. An economic trade-off study involves several steps:

(1) An estimate of the incremental effect of the task on the failure rate of the item for several different task intervals.

(2) A translation of the reduced failure rate into cost reductions.

(3) An estimate of the cost of performing the proposed task for each of the intervals considered.

(4) Determination of the interval, if one exists, at which the cost-benefit ratio is the most favorable.

e. Figure 5-7 shows a formula for evaluating the cost effectiveness of a scheduled rework task. The cost factors for inspection tasks and scheduled overhaul tasks are quite different. Scheduled removals increase both the total shop volume and the number of spare units required to replace the units that are undergoing overhaul. Consequently, unless the frequency of a very expensive failure is materially reduced by an age limit, the total cost of this task will usually outweigh its economic benefits.

f. In contrast, the total number of potential failures removed as a result of scheduled inspections is not appreciably greater than it would be if each unit were allowed to fail. Moreover, the cost of repairing potential failures is usually less than the cost of repair after a functional failure. As a result, inspection tasks, when they are applicable, are relatively easy to justify.

g. The important role of cost-effectiveness in RCM decisionmaking helps to clarify the nature of inherent reliability characteristics. The inherent reliability of an item is not the length of time it will survive without

preventive maintenance; rather, it is the level of reliability the item will exhibit when it is protected by preventive maintenance and adequate servicing and lubrication. The degree of reliability that can be achieved, however, depends on certain characteristics that are a direct result of the design details of the equipment and the manufacturing processes that produced it. These characteristics determine both the need for preventive maintenance and the effectiveness with which it can be provided.

h. The test of cost-effectiveness means that an RCM program will not include some tasks that might reduce the likelihood of noncritical failures. However, when a failure has economic consequences, the inclusion of a task that is not cost-effective would merelv transfer these consequences from one cost category to another; it would not reduce them. Thus, the cost factors on both sides must be considered inherent reliability characteristics, since they dictate the level of reliability that is feasible for an existing design. Within this framework, RCM analysis ensures all the operating reliability which is practical for the equipment. Moreover, it results in a selection of only those tasks which will accomplish this objective; hence, it also provides the required maintenance protection at minimum cost.

i. Certain of the inherent reliability characteristics of new equipment are unknown at the time a prior-to-service maintenance program is developed. Consequently, the initial program is somewhat more expensive than later refinements of it will be (although it is still a minimum-cost program in terms of the information available at the time). This situation is inevitable because of the default decision necessary to protect the equipment in the absence of full information.

Item

Annual volume of operation

Proposed interval

Average base cost of repairing a failed unit	$???	
X Number of failed units per year	X ??	
Annual base cost of repairing failed units		$???
Average cost of operational consequence failure	$???	
X Number of failures that have operational consequence	X ??	
Annual cost of operational consequences		$???
Average base cost for a time-expired unit	$???	
X Number of scheduled removals per year	X ??	
Annual total cost of time-expired units		$???
Cost of unit	$???	
X Number of spares required	X ??	
Annual cost of required spares		$???
Total Annual Support Costs Figure 5-7.		$???

A formula for analyzing the support costs associated with scheduled removals for rework. At least four proposed rework intervals must be examined to determine whether a cost-effective interval does exist.

1. It may be desirable to study a specific expensive failure mode separately.

2. Includes cost of removing and installing unit at line station and of transporting it to and from the maintenance base.

3. The number of failures with operational consequences may be different from the total, since not every failure will have such consequences.

4. If the change in volume of work at the maintenance base results in changes in facility requirements, the annual cost of such changes should be included in the support costs.

Figure 5-7. Total Annual Support Costs

CHAPTER 6

Task and Interval Selection

6-1. Task selection. Once it has been determined that scheduled maintenance is required, each failure mode must be evaluated to determine which of the available tasks will be applicable and effective. This evaluation will be done in conjunction with RCM logic questions 9 through 15 of the RCM decision diagram, see figure 4-6. The evaluation of RCM tasks can be simply explained by considering three basic questions--

a. Is a scheduled maintenance task (or combination of maintenance tasks) to detect potential failures both applicable and effective? (See para 5-8 for discussion of applicable and effective.)

b. Is an overhaul task to reduce the failure rate both applicable and effective?

c. Is a replace task to avoid failure or reduce the failure rate both applicable and effective?

The RCM philosophy requires that these questions be evaluated in this order. When one of the above tasks is found to be applicable and effective, that task is included in the preventive maintenance program, and the evaluation for that failure mode is completed with consideration for age exploration. (See chap 7.) Therefore, once a task is selected, it is not necessary to evaluate another of the three above questions.

6-2. RCM task preference.

a. The characteristics of the tasks, themselves, suggest a strong order of preference on the basis of their overall effectiveness as preventive measures. The first choice for a scheduled maintenance action is always lubricate and/or service. This is due to the necessity of replacing or adding critical fluids to the item. The next choice is a scheduled inspection, particularly if it can be performed without removing the inspected item from the equipment. This type of preventive maintenance has a number of advantages. Because scheduled inspections/tests identify individual units at the potential failure stage, they are particularly effective in preventing specific modes of failure. Hence, they reduce the likelihood of failures and operational consequences that would otherwise result from that failure mode. For the same reason, they also reduce the average cost of repair by avoiding the expensive secondary damage that might be caused by a functional failure. The fact that a scheduled inspection/test identifies individual units at the point of potential failure, means that each unit realizes almost all of its useful life. Since the number of removals for potential failures is only slightly larger than the number that would result from functional failures, both the repair costs and the number of spare units necessary to support the repair process are kept to a minimum. The scheduling of inspections, at a time when the equipment is out of service, concentrates the discovery of potential failures to the maintenance organizations that perform the

inspections. This fact, together with the lower probability of functional failures, further reduces the inventory of spare parts that would, otherwise, have to be kept available at each site. If no applicable and effective inspection/test can be found, the next choice is a scheduled adjust/align/calibrate task. These tasks may be performed as a result of an inspection or test. In that case, a scheduled adjust/align/calibrate task would not be required. One of these tasks is preferred over the next block of tasks because it allows for reuse of the item through restoration of serviceability, thereby, obtaining the maximum amount of service with minimum expenditure of resources.

b. If there is no applicable and effective inspection or adjustment, then the next choice is a scheduled overhaul. Scheduled overhaul of single parts or components leads to a marked reduction in the overall failure rate of items that have a dominant failure mode (the failure resulting from this mode would be concentrated about an average age). This type of task may be cost effective if the failures have major economic consequences. An overhaul age limit usually includes no restriction on the remanufacture and reuse of time expired units; hence, material costs are lower than they would be if the entire unit had to be discarded. Any scheduled overhaul task, however, has certain disadvantages. Because the age limit applies to all units of an item, many serviceable units will be removed that would otherwise have survived to higher ages. Moreover, the total number of removals will consist of failed units plus scheduled removals. Hence, the total workload for this task is substantially greater than it would be with inspection, and a correspondingly larger number of spares is needed to support the process. Scheduled replacement is economically the least desirable of the preventive maintenance tasks, although it does have a few desirable features, as safe life limit on simple components can prevent critical failures caused by certain failure modes. Similarly, an economic life limit can reduce the frequency of functional failures that have major economic consequences. However, a replacement task is, in itself, quite costly. The average life realized by an item subject to a safe life limit is only a fraction of its potentially useful life, and the average life of an item subject to an economic life limit is much less than that of many individual units. In addition, a replacement task involves the cost of replacement, as new items or parts must be purchased to replace the time-expired units, since a life limit usually does not permit remanufacture and reuse.

6-3. Determination of maintenance intervals.

a. Once the RCM logic has been applied and a decision has been reached on the type of maintenance to be performed, then safety and cost considerations must be addressed to establish the maintenance intervals. Scheduled inspections and replacement intervals should coincide whenever possible to reduce the impact on the user. This section presents the considerations that must be addressed when establishing intervals for inspection/test and replacement monitoring and analyzing the cost of unit monitoring and analyzing the cost of unit maintenance.

b. Following are the general considerations to be addressed for each of the above categories:

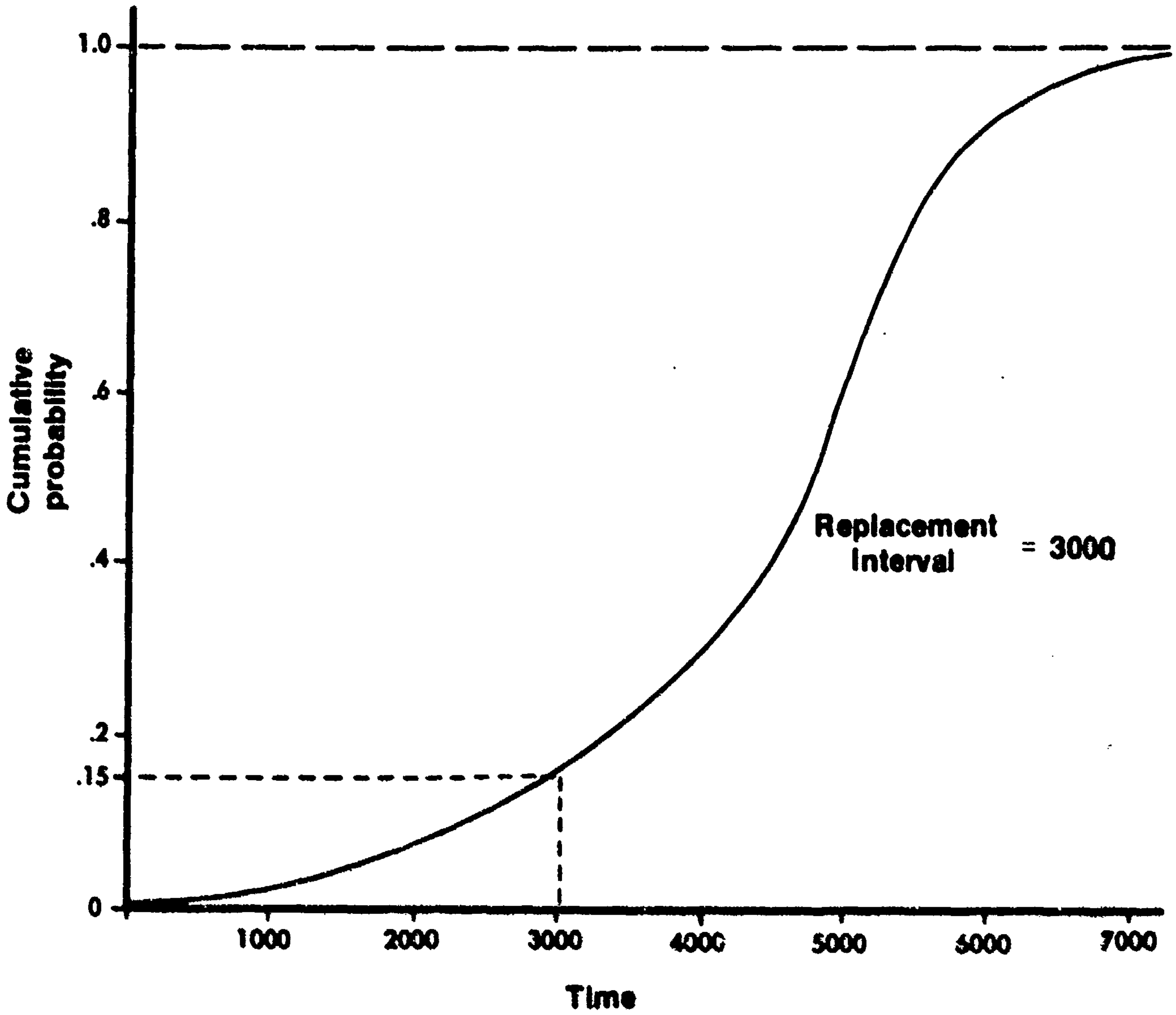

Figure 6-1. Cumulative failure distribution

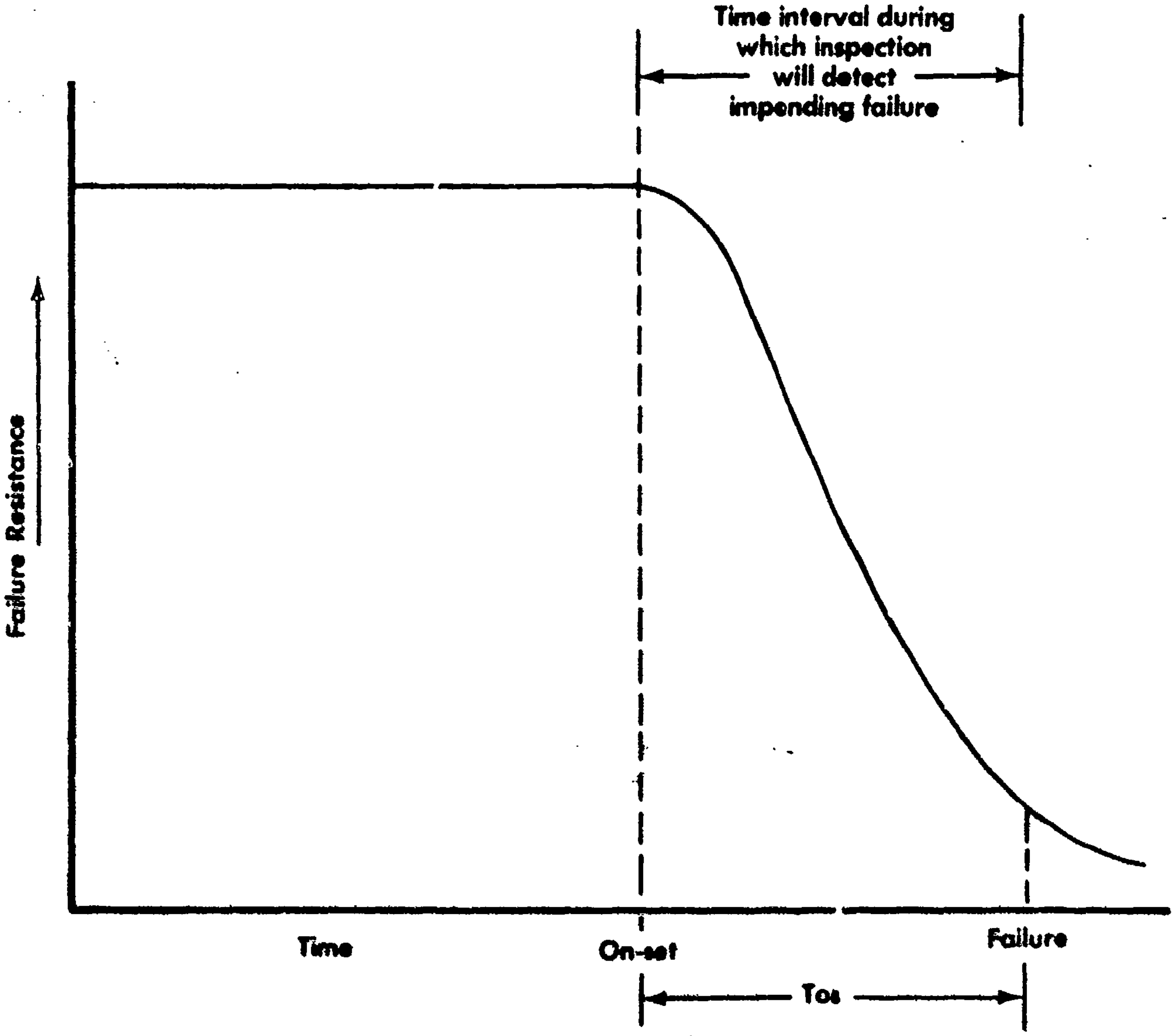

Figure 6-2. Example of Tos

(1) Replacement limits.

(a) Replacement limits are established for items where inspection/tests or unit maintenance is not feasible from a safety or cost-effectiveness standpoint (e.g., does not provide adequate assurance of detection prior to failure).

(b) Replacement limits are established as a prerequisite for assuring safety or cost-effectiveness. The general techniques to be followed in establishing hard time replacement intervals are as follows:

1. Safety consideration.

a. MIL-STD-882, System Safety Program for Systems and Associated Subsystems and Equipment: Requirements for, prescribes requirements governing safety.

b. AR 385-55, Prevention of Motor Vehicle Accidents, describes vehicle safety standards. These standards should be addressed during the analysis.

c. The safety replacement interval is usually established by first establishing the cumulative failure distribution for the item (this distribution can usually be obtained from empirical test data or from reliability predictions), and then establishing a replacement interval which results in an extremely low probability of failure prior to replacement. Figure 6-1 shows an example of how a replacement interval can be established for safety considerations. The cumulative failure distribution was established for the component and then the resulting limit was determined which would provide an 85 percent probability that the component would not fail prior to replacement.

d. The replacement interval for the component falls within the anticipated service life of the system. If the limit exceeds the service life, preventive replacement is not required.

2. Cost and effectiveness consideration.

a. Where the failure does not cause a safety hazard but rather causes mission failure, the replacement interval is established in a trade-off process involving the cost of replacing components, the cost of a failure, and the readiness requirement of the equipment/system.

b. The process of establishing the replacement interval (Tr) is accomplished through minimization of the following cost equation:

$$C(Tr) = (Cpr + Cf(F(Tr)))/Tr$$

where

C(Tr) = Expected cost per unit time.

Cpr = Cost of a preventive replacement.

Cf = Cost of a failure (Includes cost of part replacement and system downtime). The suggested methodology for calculating the cost of system downtime, e.g., C_{op} (cost of lost operational time per year). This could be modified to the cost of lost operational time per failure, e.g., number of operational hours lost per failure X C_{oh}. If Cf = Cpr then cost is not a determining factor. The value of Tr should be established based on mission requirements.

C_{oh} = Cost overhaul.

F(Tr) = Expected number of failures in interval Tr.

Tr = Replacement interval.

c. Depending upon the equation defining the failure distribution, this equation can be solved by differentiation or by iteration (substituting different values for Tr and calculating the resultant expected cost).

d. After the minimum-cost replacement interval has been established, the effects on system downtime should be reviewed to assure an acceptable readiness rate is achieved.

3. Other considerations. In the establishment of scheduled replacement intervals, one must note the desirability of consolidating several scheduled replacements to occur at the same interval. A minimization of the summations of the individual costs is then sought. The minimization formula previously presented can be used in summation to establish this group scheduled replacement interval. However, if the intervals are relatively close to each other, a mean interval may be selected and used if the effects on the cost and readiness of individual items are not materially affected. (Where degradation in readiness or cost is not prohibitive, consideration should be given to establishing mission-related replacements to occur concurrent with safety related replacement.)

(2) Scheduled maintenance.

(a) Scheduled maintenance is established for those items where operator/crew monitoring is not feasible from a safety or cost-effective standpoint.

(b) Scheduled maintenance intervals are established for two purposes: to locate imminent failures and to detect the occurrence of a failure. In either of these cases, the consequence of a failure may be a safety hazard or mission abort.

(c) Scheduled maintenance--detect imminent failures.

1. The failure characteristics of an item which would use scheduled maintenance as a preventive procedure has two distinct failure distributions. The first distribution is that dealing with time to onset of a failure; i.e., the distribution of time until evidence of imminent failure can be detected. The second distribution deals with the time from onset to occurrence of the failure. (See fig 6-2.)

2. Safety consideration.

a. The objective of scheduled maintenance, in this instance, is to schedule the inspections so that there is a very low probability that a failure will occur between inspections. This probability of failure is composed of the probability that failure onset will occur, and the onset will go to failure all within the inspection interval. If the average time to onset is much larger than the average time from onset to failure, consideration should be given to establishing a usage dependent inspection program, i.e., wait to start inspections until the item has obtained a certain amount of usage. Of course, such usage dependent intervals would only be feasible where usage information is maintained by the field on the item under consideration.

b. If on the item usage information is not routinely maintained by the field, then the distribution of time from onset to failure becomes the fundamental consideration in establishing the inspection interval.

3. Mission consideration.

a. Where the failure does not cause a safety hazard, but rather causes a mission failure, the inspection interval is established in a trade-off process involving the cost of conducting inspections, the cost of a failure, and the readiness requirement of the equipment/system.

b. The process of establishing the inspection interval (Ti) is accomplished through minimization of the following cost equation:

$$C(Ti) = [Ci + Cfu\,(F(Ti))]/Ti$$

where

C(Ti) = Expected cost per unit time.

Ci = Cost of an inspection.

Cfu = Cost of an undetected failure (i.e., cost of the end item operating in a degraded mode).

F(Ti) = Expected number of failures in interval Ti.

The Operational Mode Summary/Mission Profile could be used as a basis for determining the cost of an undetected failure, e.g.:

MISSION	AVG DAILY USE	EXPECTED LIFE (360 DA/YR)	COMPONENT COST
MOVE	5 Miles	20 Yrs	$2,350,000
SHOOT	2 Rounds	10 Yrs	175,000
COMMUNICATE	1 Hr	10 Yrs	12,000
		TOTAL WEAPON SYSTEM	$2,537,000

$$Cfu = \frac{2,350,000}{(20 \times 360)}$$

$$= \frac{2,350,000}{72,000}$$

$$= \$326.39$$

NOTE: This example assumes the system would not be able to move for 1 day.

c. Depending upon the equation defining the failure distribution, this equation can be solved by differentiation or iteration (substituting different values for Ti and calculating the resultant expected cost).

d. After the minimum cost inspection interval has been established, the effects on system downtime should be reviewed to assure an acceptable readiness rate is achieved.

4. In establishing inspection intervals, one must consider the desirability of arranging several inspections to occur at the same interval. A minimization of the summation of the individual cost is then sought. The minimization formula previously presented can be used in summation to establish this group inspection interval. However, if inspection intervals are relatively close to each other, a mean interval may be selected if cost/readiness of individual items are not materially affected (where degradation in readiness or cost is not prohibitive, consideration should also be given to scheduling the mission-related inspections to occur simultaneously with related inspection).

(d) Scheduled maintenance--detect failures.

1. Safety consideration.

a. If this RCM option is acceptable, the failure is such that injury does not immediately result with failure, but the chance of injury increases the longer the failure goes undetected.

b. The object is, thus, to establish an inspection interval where the expected time that a failure would go undetected is within acceptable bounds. If the failure density function is known, it should be used to establish the inspection interval.

c. In cases where the density function is not known or is not amenable to mathematical manipulation, the expected time that failure goes undetected can be

approximated by one half of the product of the probability that a failure occurs and the inspection interval.

2. Mission consideration.

a. Where the failure does not cause a safety hazard, but rather causes mission failure, the inspection interval is established in a trade-off process involving the cost of inspection, the cost of an undetected failure, and the readiness requirement of the equipment/system.

b. The process of establishing the inspection interval (Ti) is accomplished through minimization of the following cost equation:

$$C(Ti) = [Ci + Cfu\ (Ti)_{fu}]/Ti$$

where

C(Ti) = Cost per unit time

Ci = Cost of an inspection

Cfu = Cost per unit time of an undetected failure (i.e., cost to the mission per unit time due to end item operating in a degraded mode).

$(Ti)_{fu}$ = Expected period of time that a failure would go undetected in inspection interval Ti

c. Depending upon the equation defining the failure distribution, this equation can be solved by differentiation or by iteration (substituting different values for Ti and calculating the resultant expected cost).

d. After the minimum cost inspection interval has been established, the effects on system downtime should be reviewed to assure an acceptable readiness rate is achieved.

3. In establishing inspection intervals, one must consider the desirability of arranging several inspections to occur at the same interval. A minimization of the summation of the individual cost is then sought. The minimization formula previously presented can be used in summation to establish this group inspection interval. However, if inspection intervals are relatively close to each other, a mean interval may be selected if cost/readiness of individual items are not materially affected (where degradation in readiness or cost is not prohibitive, consideration should also be given to scheduling the mission-related inspections to occur simultaneously with related inspections).

(3) Operator/crew monitoring.

(a) Operator/crew monitoring is the process where the operator/crew detects either experienced or impending failure through routine monitoring of the operation and use of the item. The experienced failures are those that are

detected by the operator/crew when or after they occur. The impending failures are those detectable before serious degradation occurs. Both types are detectable directly, by the operator/crew, through the human senses (sound, touch, sight, etc.), or indirectly, through the incorporation of design features such as built-in test equipment (BITE) and sensors/transducers (warning lights, gauges, etc.).

(b) Operator/crew monitoring is generally the most desirable of the types of preventive maintenance requirements, as it will result in the least number of maintenance actions. However, a high degree of operational availability or safety may require the inclusion of scheduled maintenance or component replacement to augment operator/crew monitoring.

(c) The cost of operator/crew monitoring must be [illegible] for impending and experienced failures so that a comparison to scheduled and hard time can be made. There should normally be low cost associated with an operator/crew monitor system. The operator/crew is already assigned to a system and, through performance of normal duties, impending and experienced failures can be detected. Whenever operator/crew monitoring is a cost alternative, it should be the most effective. The cost equation for operator/crew monitoring is--

$$C_{(cm)} = \left(\frac{C_{rd}}{N_a} + C_m\right) + (C_{fu})\,(F_{tu})$$

Where $C(cm)$ = Expected cost of undetected failures in life of system for crew monitoring.

C_{rd} = Cost of research and development for monitoring system.

N_a = Number of weapon systems/end items to be acquired.

C_m = Cost of monitoring system.

C_{fu} = Cost of undetected failure.

F_{tu} = Number of failures undetected over the life of the system.

(d) The probability that a failure can be detected by operator/crew monitoring, either impending or experienced, will be determined from the FMECA or historical data. This probability is comprised of factors such as the probability of the warning device, if included, detecting a failure and emitting a signal, and the probability of the operator/crew perceiving the signal.

(e) The readiness would be calculated for either case of operator/crew monitoring: without a warning device, and with a warning device. These values and the cost estimates would be traded off with those obtained from scheduled, hard time, or a combination of any of the three, to determine the optimum maintenance requirement.

CHAPTER 7

Age Exploration

7-1. Age exploration.

a. The Age Exploration Program is an essential part of the overall RCM program. Any complex equipment generates failures, and failure events will occur throughout its operating life. The response to these events depends on the failure consequences. If a failure that is not anticipated has serious implications for safety, the first occurrence sets in motion an immediate cycle of maintenance and design changes. In other cases, waiting until several failures have occurred, allows a better assessment of their frequency to determine the economic benefits of preventive tasks or possible redesign. Very often, waiting until enough failures have occurred to permit an evaluation of age reliability relationships provides the information necessary to modify the initial maintenance decisions. Evolution of the preventive maintenance program does not consist solely of reactions to unanticipated failures. The information that becomes available, including the absence of failures, is also used for systematic evaluation of all tasks in the initial program. On the basis of actual data, the initial conservative intervals for scheduled inspections can be adjusted and the applicability of scheduled rework and economic life tasks can be investigated. Actual operations will frequently confirm the assessments of failure consequences, but occasionally the consequences will be found to be more serious or less serious than anticipated, or a failure thought to be evident to the operating crew is not, and vice versa. The process by which all this information is obtained is called age exploration, both because the amount of information is a direct function of the age of the equipment in service and because some of this information relates to the ages of the items themselves.

b. Age exploration is the process of determining the reliability characteristics of the equipment under actual operating conditions, which begins the day a new item enters service. This process includes monitoring the condition and performance of each item, analyzing failure data to identify problems and their consequences, evaluating inspection findings to adjust task intervals, and determining age reliability relationships for various items. Since the decision process that led to the initial preventive maintenance program was based on prior to service information, the program will reflect a number of default decisions. As operating experience begins to produce real data on each item, the same decision logic can now be used to respond to failures not anticipated, assess the desirability of additional tasks, and eliminate the cost of unnecessary and over intensive maintenance resulting from the use of default answers. In the pamphlet, certain aspects of age exploration, as they relate to task intervals and the intensive study of individual items in the systems, powerplant, and structures divisions, are considered. In a broad sense, however, age exploration encompasses all reliability information on the item as it ages in service. Thus, the heart of an ongoing maintenance program is the collection and analysis of this information, whether by the engineering organization or by a separate group. Although intensive age exploration of individual items plays a direct role in assessing their maintenance requirements, this is only one of many sources of reliability information. In the case of aircraft, it is also not the

information of most immediate concern. In order to respond to problems not anticipated, an operating organization must have some means of identifying those that require first priority. On this basis, a ranking of the various types of reliability data according to the priority of failure consequences is listed--

(1) Failures that could have a direct effect on safety.

(2) Failures that have a direct effect on operational capability, either by aborting the mission or by restricting its continuation.

(3) The failure modes of units removed as a result of functional failures.

(4) The causes of potential failures found as a result of scheduled inspections.

(5) The general condition of unfailed parts in units that have failed.

(6) The general condition of parts in units removed specifically for sampling process.

7-2. The uses of operating data. It is important to recognize, that in planning a prior to service program and at the age exploration stage, a fleet of equipment does not materialize overnight. The number of items/systems in service and the associated volume of operations build up slowly. This allows us to concentrate first on the most frequent failures (since those that occur early will continue to occur early after either delivery or repair) or on those failures with the most serious consequences. As the volume of operations increases, the less frequent failures come to light and can be dealt with later. This latter information may be obtained by deliberate heavy use of the first few pieces of equipment, the fleet-leader concept, although the small size of the sample data presents a serious drawback. The reliability information obtained from actual operating experience is quite varied. Although the failure rate plays a role early in operation in pinpointing design problems and evaluating task-effectiveness, an age exploration program is organized to provide the following kinds of information:

a. The types of failures the equipment is actually exposed to, as well as their frequencies.

b. The consequences of each failure, ranging from direct safety hazards through serious operational consequences, high repair costs, long out of service times for repair, to a deferred need to correct inexpensive functional failures.

c. Confirmation that functional failures classified as evident to the operating crew are, in fact, evident during normal performance of duties.

d. Identification of the circumstances of failure to determine whether the failure occurred during normal operation or was due to some external factor, such as bird strike.

e. Confirmation that scheduled inspections are really measuring the reduction in resistance to a particular failure mode.

f. The actual rates of reduction in failure resistance to determine optimum inspection intervals.

g. The mechanism involved in certain failure modes to identify new forms of scheduled inspection and parts that require design improvement.

h. Identification of tasks assigned as default actions in the initial program which do not prove applicable and effective.

i. Identification of maintenance packages that are generating few trouble reports.

j. Identification of items that are not generating trouble reports.

k. The ages at which failures occur, so that the applicability of scheduled overhaul and remove/replace tasks can be determined by statistical analysis.

Figure 7-1 summarizes the use of information in the age exploration process as it relates to the overall preventive maintenance program. This table shows the processes which must take place during the evolution of the maintenance program.

7-3. Modifying the Maintenance Program. The nature of the major subassemblies in the item leads to different patterns in their maintenance requirements, and hence, in the decision paths used to arrive at an initial set of scheduled tasks. For the same reason, age exploration activities in the major divisions (structure, power plant, etc.) tend to focus on different sources of reliability information. In some cases, the study of individual items involves no specified age limits; in others, it involves limits that are moved freely and rapidly on the basis of inspection findings. The essential factor in all cases is not the existence of an age limit, but knowing the age of each unit of the item examined.

a. Age exploration of systems items. The systems division consists of a large number of readily replaceable complex items and their relatively simple fixed connecting lines. Usually, an initial systems program includes few preventive maintenance tasks other than servicing and failure finding inspections, and there are rarely defined age exploration requirements, as in the powerplant and structure programs. The cost of corrective maintenance is fairly low for most components and, when operating data indicate that additional preventive tasks are justified, it is generally because of an unexpectedly high failure rate that involves operational consequences. In some cases, the failure rate may be high enough to warrant the replacement of certain components with more reliable ones. Since the reliability of components, on the whole, tends to be low, the principal age exploration tool in the systems division is actuarial analysis of failure data. Ordinarily, the conditional probability of failure for a complex item is not expected to vary much with operating age. However, a newly designed system will sometimes show a dominant failure mode that is both age-

RESULTS OF AGE EXPLORATION

REFINEMENTS OF INITIAL MAINTENANCE PROGRAM			MAJOR REVISIONS TO INITIAL MAINTENANCE PROGRAM		
INSPECTION TASKS			RESULTS OF TECHNOLOGICAL CHANGE		
PROPOSED SCHEDULED MAINTENANCE TASKS	PROPOSED AGE LIMIT TASKS	ITEMS ASSIGNED TO NO PREVENTIVE MAINTENANCE	UNANTICIPATED FAILURE MODES OR CONSEQUENCES	NEW OR REDESIGNED ITEM	CHANGES IN INSPECTION TECHNOLOGY
Confirm that reduction in failure resistance is visible.	Determine age reliability relationship to confirm that conditional probability if failure increases with age.	Monitor and evaluate operational data to see whether some applicable and effective task can be developed.	Develop scheduled maintenance tasks to prevent critical failure and to prevent or reduce frequency of expensive failures at low ages.	Conduct RCM analysis of item when it first enters service.	Evaluate applicability and effectiveness of new techniques.
Determine rate of reduction in failure resistance.	If failures are age-related, determine whether a cost-effective age limit exists.		Develop design changes necessary for permanent correction or problems.	Refine maintenance requirements through age exploration.	
Confirm or modify potential failure condition.	If a cost-effective interval can be found, add task to program.		Develop failure findings tasks for hidden functions not identified in initial program.		
Adjust inspection interval and age for first inspection, if applicable			Develop scheduled maintenance requirements or other tasks to control critical or expensive failures at high ages, where produce improvement may not be economically justified.		

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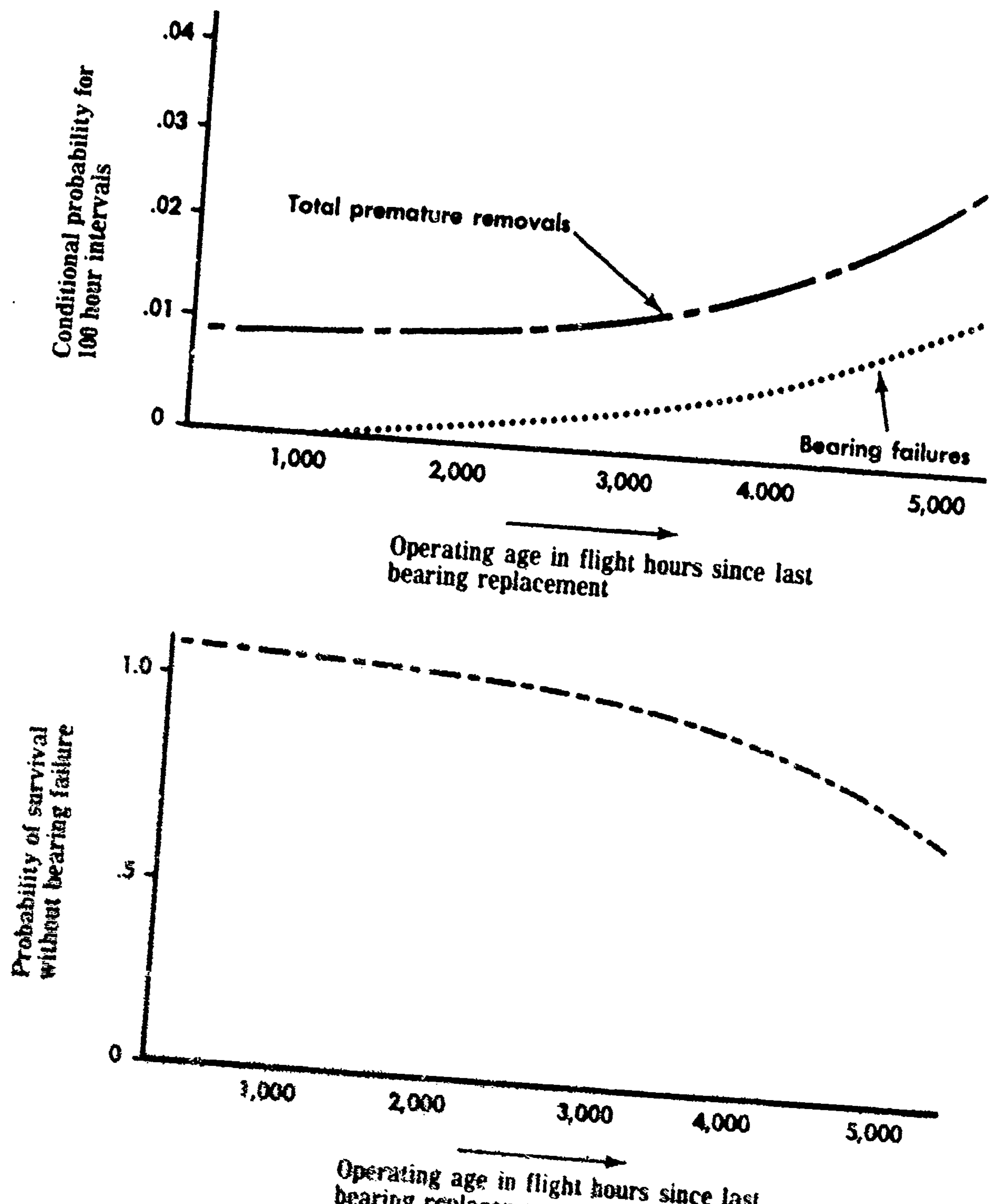
Figure 7-1. **Summary of the age exploration process**

related and expensive enough to make an age limit task desirable. Figure 7-2 shows a conditional probability curve derived from operating experience with an engine driven generator. There is little change in the failure rate until about 2,000 hours, when the bearing starts to fail; thereafter, the conditional probability of failure increases with age as this failure mode becomes more dominant. The survival curve in figure 7-2 shows the probability that a generator will not suffer a bearing failure.

(1) Failure examples. Bearing failures cause such extensive damage to a generator that the entire generator must be scrapped and replaced with a new one, at a high cost. The bearing itself is relatively inexpensive. In this case a cost analysis showed that it would be desirable to assign an economic life replacement task to the bearing at an interval of 4,000 hours. Such a task could also be viewed as a scheduled overhaul task for the generator, with the overhaul specification including discard and replacement of the bearing. The generator and bus-tie relay were assigned a scheduled rework task for a different reason. The relay is a complex mechanical item, and its basic functions are to convey the power from each generator to its own load bus and to convey ground power to the individual load buses. A failure of either of these functions will be reported by the operating crew and will result in removal of the faulty relay for repair. The relay also has a number of secondary functions, some of which are hidden. When older units began coming into the shop for repair, many of the hidden functions were found to be in a failed state; in addition, many of the parts were so worn that the units could no longer be repaired. On this basis, the relay was assigned a replacement at a maximum age limit of 14,000 hours for shop disassembly to the extent necessary for repair. This task was intended primarily to protect the important hidden functions, but the savings in repairable units, in this case, more than offset the expense of scheduled removals. Although failures not anticipated in the systems division rarely involve safety, some failures do have serious enough consequences to be treated as if they were critical. One such case was a failure of a landing gear actuator endcap. The endcap was designed to have a fatigue life longer than the expected service life of the aircraft, and since corrosion was not expected to be a problem with this item, the only task assigned in the initial program was an inspection of the cap whenever the actuator was in the shop for repair. A check for internal hydraulic leaks had also been discussed, but it was considered unnecessary for this type of actuator. Unfortunately, this actuator is not removed as part of the landing gear, and it has a very low failure rate. Consequently, no inspections had been performed. The endcap actually experiences two failures in operation. These failures originated in the exposed internal portion of the endcap, where an O-ring is used to seal in the hydraulic fluid. The original design and assembly techniques had allowed moisture to accumulate between the cap and body of the actuator (on the air side of the O-ring), causing pitting corrosion. When the endcap separates from the actuator, all the hydraulic fluid is lost from the number 3 hydraulic system, and the landing gear cannot be retracted. If this failure occurred during flight, the gear in the failed position would rest on the doors, and when the pilot extended the landing gear, all three gears would simply free fall to the down and locked position. However, if the gear doors were also to fail, the failed gear would free fall through the opening, and in the extreme case at high speed, the door could separate and fall to the ground. This multiple failure would be considered critical. While neither of the two endcap



NOTE: The results of actuarial analysis of operating experience with the engine driven generator.

Figure 7-2 Conditional probability curve of an engine-driven generator.

failures, in themselves, were classified as critical, the action taken was similar to that for an unanticipated critical failure. First, a safe life limit was established for the endcap, and a modified part with greater fatigue life was designed. This modified cap was installed at or before the existing caps reached the present life limit. Second, all actuators were removed and sent to the shop for upgrading. Each actuator is disassembled, the endcap is replaced with the new part, corrosion on other parts of the actuator is removed, and improved corrosion protection materials are applied upon reassembly. Failure data are also the basis for adjusting task intervals for hidden functions in systems items. Many of the failure finding tasks are based on opportunity samples, tests, or inspections of hidden functions on units sent to the shop for other repairs. The results of these inspections are recorded and analyzed to find the inspection interval that will provide the required level of availability at the lowest inspection cost. The units tested in the shop are considered to be a random sampling of the units in the operating fleet. Thus, the percentage of failures found in the shop tests can be taken as the percentage of failures that would be found throughout the fleet. Failure finding inspections of items installed on the aircraft are performed at scheduled intervals. In this case, the percentage of failures found will represent approximately twice the percentage expected in the entire fleet, because the inspection occurs at the end of the assigned interval, rather than at random times after the preceding inspection.

b. Age exploration of powerplant items. Age exploration is an integral part of any initial powerplant program. A completely new type of engine, often incorporating new technology, is sometimes unreliable when it first enters service. During the first few years of operation, premature removal rates are commonly high. The high removal rate makes it possible for the maintenance shop to obtain information not only on the parts involved in the failure, but on the condition of other parts of the engine as well. Most new aircraft engines experience unanticipated failures, some of which are serious. The first occurrence of any serious engine failure immediately sets in motion a developmental cycle. The cause of the failure is identified, and a scheduled task is devised to control functional failures until the problem can be resolved at the design level. Modified parts are then incorporated in the operating fleet, and when continued inspections have shown that the modification is successful, the special task requirements are terminated.

c. Age exploration of structural items. Whereas, systems and powerplant items are designed to be interchangeable, there is no simple way of replacing most structural elements. Repairs and even detailed inspection of internal parts of the structure involve taking the equipment out of service, sometimes for an extended period. For this reason, structural items are designed to survive to much higher ages than systems or powerplant components. Nevertheless, initial intervals in the structural inspection plan are only a fraction of this design life goal, both because of the consequences of a structural failure, and because of the factors that can affect the design fatigue life in individual equipment. These include variations in the manufacturing process, overloads encountered by individual equipment, loading spectra that differ from the standards employed by the designer, environmental conditions causing corrosion, and accidental damage from foreign objects. In the structure division, the inspection program is the

vehicle for age exploration. Thus the initial intervals are intended not only to find and correct any deterioration that may have occurred, but also to identify the age at which deterioration first becomes evident for each structural item. The inspection findings and work performed are monitored by engineers who record all the relevant findings on those systems designated as inspection samples. With this information, there is a good basis in the ongoing program for revising the age at which inspections of structurally significant items should begin in later delivery. In general, the interval to the first inspection in the initial program is the same as the interval for repeat inspections, and successive inspections are performed on each system as it ages to identify the age at which deterioration first becomes evident. Their procedure provides adequate information for short intervals in relation to the fatigue life design goal. Inspection of an item at intervals of 5,000 hours, for example, will result in documentation of its condition at total ages of 5,000 hours, 10,000 hours, 15,000 hours, and so on. However, if an item is assigned an initial interval of 20,000 hours, subsequent inspections at total ages of 40,000 and 60,000 hours would leave great gaps in the flow of age condition information. It is, therefore, necessary to schedule inspections of several systems at intermediate ages to ensure that the age at which any deterioration begins can be identified within a close enough range for the information to be useful. The items that are assigned such long intervals, of course, are those which not only have very little effect on residual strength, but also have a very low susceptibility to corrosion and other damage. Because it takes several years for a fleet to build up, it is always hoped that the conservative start of inspection intervals in the initial program will apply only to the first few end items to reach these ages. It is also hoped that inspection findings will support an increase in the ages at which the first inspections are performed on subsequent items entering the fleet. This increase is usually accomplished by "forgiving" the first few inspections in the sequence rather than by changing the interval. The information obtained from the inspections is supplemented by data from the manufacturer's continuing fatigue tests, as well as by inspection information from other operating organizations. Once the first evidence of deterioration does appear, this new information may indicate that adjustment of the repeat interval itself would be desirable. When early deterioration appears in a structural item, low start of inspection and repeat intervals must be defined and maintained until design changes have been incorporated that avoid the need for such early and frequent inspections.

d. A relatively small number of sample inspections may be adequate for economic purposes. For example, suppose an item has a relatively short average fatigue life of 60,000 hours. In a sample of 10 items all of the same total age, the probability of discovering this defect by 50,000 hours is .63, and the same defect would be expected to appear at this age in 10 percent of the uninspected items. In practice, the sample inspections are performed on highest age items, and when a defect is discovered, its incidence in the lower age items in the fleet will be much less than 10 percent. When a large number were to be inspected at a fixed major inspection interval, it was common practice to inspect items of relatively low significance on a fraction of the fleet (every fifth one) and this practice was referred to as fractional sampling.

Once the sampling inspections have identified the age at which an item begins to show signs of deterioration, some action must be taken. This may be an increase in the number of items sampled, perhaps to 100 percent, or it may be treatment or modification of the affected area to forestall deterioration in others. As the fleet ages, more of the sampling inspections will revert to 100 percent inspections, unless such basic preventive measures are taken. Quite apart from problems associated with higher ages, there is always the possibility of a failure of a structural item that is not anticipated at more modest ages, just as there is for systems and powerplant items. Note that this embodies the concept of a long initial interval followed by short repeat intervals. The continuing age exploration of damage tolerant structure will lead to the same results. Once the age at which fatigue damage becomes evident has been identified for each item, there will be either short inspection intervals starting at this age, or a design modification that extends the fatigue life of the item, making the inspection task unnecessary. The decision to modify an item's structure depends on its remaining technologically useful life. When it is likely to be outdated soon by new designs, it is usually difficult to justify structural modifications on economic grounds, and it may be necessary to perform frequent inspections of items that have been identified as approaching their fatigue lives. In this case, there is an increasing likelihood that the detection of a fatigue crack will also take the item out of service for repair. and if the cost of repair cannot be justified, it may be necessary to retire it. Whenever an active modification policy is not followed, the frequency of repair and the number of out-of-service incidents will be a direct function of the increasing age. It is frequently considered axiomatic that all structural inspections must be intensified when an item reaches higher ages. However, this has not necessarily been the experience with some items because of the policy of modifying items as soon as they are identified as nearing their fatigue lives. Consequently, in decisions concerning fleet retirement, the cost of maintaining structural integrity has been secondary to such factors as fuel consumption, performance, and payload and range capability. When a safe life structural item reaches its defined life limit, there is usually no alternative to replacing it with a new one. Thus, an item designed to safe life structure criteria must have greater economic viability than one designed as a damage tolerant structure in order to justify the more expensive procedures that are required for continued operation.

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Appendix A

References

Section 1
Required Publications

AR 70-1	Army Research, Development, and Acquisition
AR 385-55	Prevention of Motor Vehicle Accidents
AR 700-127	Integrated Logistics Support
AR 750-1	Army Materiel Maintenance Concepts and Policies
AR 750-37	Sample Data Collection: The Army Maintenance Management System
DARCOM-R 750-8	Implementation of Reliability Centered Maintenance
DOD D 4151.16	DoD Equipment Maintenance Program
DOD D 5000.39	Acquisition and Management of Integrated Logistic Support for Systems and Equipment
MIL-HDBK-472	Maintainability Prediction
MIL-STD-109	Quality Assurance Terms and Definitions
MIL-STD-280	Definitions of Item Levels, Item Exchangeability, Models, and Related Terms
MIL-STD-470	Maintainability Program for Systems and Equipment
MIL-STD-721	Definitions of Terms for Reliability and Maintainability
MIL-STD-756	Reliability Modeling and Prediction
MIL-STD-785	Reliability Program for Systems and Equipment Development and Production
MIL-STD-882	System Safety Program Requirements
MIL-STD-1388-1A	Logistic Support Analysis
MIL-STD-1388-2A	DoD Requirements for a Logistic Support Analysis Record
MIL-STD-1629	Procedures for Performing a Failure Mode, Effects, and Criticality Analysis

Appendix A--Continued

Section II
Related Publications

AFLG-AFSC Reg 66-35	Equipment Maintenance - Scheduled Maintenance Program
AR 702-3	Army Materiel Systems Reliability, Availability and Maintainability (RAM)
AR 750-22	Army Oil Analysis Program
AR 750-43	Test, Measurement and Diagnostic Equipment
DA Pam 750-40	Concepts of Reliability Centered Maintenance
DARCOM-R 750-9	RCM - Application to Depot Maintenance Work Requirements
MIL-STD-2080	Maintenance Engineering, Planning, and Analysis for Aeronautical Systems, Subsystems, Equipment, and Support Equipment
MIL-HDBK-266	Application of RCM to Naval Aircraft Weapon Systems and Support Equipment

Explanation of Abbreviations and Terms

Section I

Abbreviations

AMC	Army Materiel Command
BIT	Built-in-test
BITE	Built-in-test equipment
CA	Criticality analysis
Cbr	Cost benefit ratio
Ccm	Cost of corrective action
Cfu	Cost of undetected failure
Ci	Cost of inspection
Cm	Crew monitoring
COEA	Cost and operations-effectiveness analysis
Coh	Cost of an operating hour
Cop	Cost of lost operation
Copc	Cost of operating consequences
Cpm	Cost of preventive task
Cpr	Cost of preventive replacement
DA	Department of the Army
DMMH	Direct maintenance man-hours
DoD	Department of Defense
Dt	Development testing
F	Failures
FMECA	Failure mode, effects, and criticality analysis

Glossary (continued)

FSD ---------------------- full-scale development

ILS ---------------------- integrated logistics support

ILSA ---------------------- integrated logistics support analysis

LOA ---------------------- letter of agreement

LSA ---------------------- logistics support analysis

LSAR ---------------------- logistics support analysis record

LSP ---------------------- logistics support plan

MAC ---------------------- maintenance allocation chart

MSC ---------------------- major subordinate command

MSG ---------------------- maintenance steering group

MTBF ---------------------- mean time between failures

Na ---------------------- Number of weapon systems to be acquired

Nt ---------------------- Number of proposed preventive tasks

Ot ---------------------- operational testing

PMD ---------------------- program management document

RCM ---------------------- reliability-centered maintenance

RD ---------------------- research and development

SCP ---------------------- systems concept paper

SHSC ---------------------- safety hazard severity codes

Ti ---------------------- inspection interval

TOA ---------------------- trade-off analysis

TOD ---------------------- trade-off determination

Tr ---------------------- replacement interval

Glossary (continued)

Section II

Terms

Age Exploration. A systematic evaluation of an item based on analysis of collected information from in-service experience. It assesses the item's resistance to a deterioration process with respect to increasing age.

Acquisition Phases.

a. Concept exploration phase. The identification and exploration of alternative solutions or solution concepts to satisfy a validated need.

b. Demonstration and validation phase. The period when selected candidate solutions are refined through extensive study and analyses; hardware development, if appropriate; test; and evaluations.

c. Full-scale development phase. The period when a system and the principal items necessary for its support are designed, fabricated, tested, and evaluated.

d. Production and deployment phase. The period from production approval until the last system is delivered and accepted.

Catastrophic failure. A failure which may cause death or weapon system loss, e.g., aircraft, missile, tank, ship, etc. This is the same as SHSC 1.

Corrective action. A documented design, process, procedure, or materials change implemented and validated to correct the cause of failure or design deficiency.

Corrective maintenance. The actions performed, as a result of failure, or potential failure, to restore an item to a specified condition.

Critical component. The item identified in the equipment/system whose failure may result in a mission abort, mission failure, personal injury, or equipment damage, or loss of function required by regulation or statute.

Critical failure. A failure which may cause severe injury, major property damage, or major system damage which will result in mission abort. This is the same as SHSC 2.

Criticality. A relative measure of the consequences of a failure mode and its frequency of occurrences.

Criticality analysis (CA). A procedure by which each potential failure mode is ranked according to the combined influence of severity and probability of occurrence.

Glossary (continued)

Design parameters. Qualitative, quantitative, physical, and functional value characteristics that are inputs to the design process, for use in design tradeoffs, risk analyses, and development of a system, that is responsive to system requirements.

Deterioration. Degradation in quality, mission accomplishment, and/or reliability due to age, usage, or environment.

Detection mechanism. The means or methods by which a failure can be discovered by an operator under normal system operation or can be discovered by the maintenance crew by some diagnostic action.

End item. A final combination of end products, component parts, and/or materials which is ready for its intended use; e.g., ship, tank, mobile machine shop, aircraft.

Environments. The conditions, circumstances, influences, stresses and combinations thereof, surrounding and affecting systems or equipment during storage, handling, transportation, testing, installation, and use in standby status and mission operation.

Failure. Any deviation from the design-specified, measurable tolerance limits that cause either a loss of function or reduced capability.

Failure cause. The physical or chemical processes, design defects, quality defects, part misapplication, or other processes which are the basic reason for failure or which initiate the physical process by which deterioration proceeds to failure.

Failure effect. The consequence(s) a failure mode has on the operations, function, or status of an item. Failure effects are classified as local effect, next higher level, and end effect.

a. Local effect - The consequence(s) a failure mode has on the operation, function, or status of the specific item being analyzed.

b. Next higher level effect - The consequence(s) a failure mode has on the operation, functions, or status of the items in the next higher indenture level above the indenture level under consideration.

c. End effect - The consequence(s) a failure mode has on the operation, function, or status of the highest indenture level.

Glossary (continued)

Failure mode. The manner by which a failure is observed. Generally describes the way the failure occurs and its impact on equipment operation.

Failure mode and effects analysis (FMEA). A procedure by which each potential failure mode in a system is analyzed to determine the results or effects thereof on the system and to classify each potential failure mode according to its severity.

Failure modes, effects, and criticality analysis (FMECA). An analysis to identify potential design weaknesses through systematic, documented consideration of the following: all likely ways in which a component or equipment can fail; causes for each mode; and the effects of each failure and may be different for each mission phase.

Function. The characteristic actions of units, systems, and end item.

Functional test. The quantitative evaluation of a system or component to assure its ability to perform over the full operating range as designed, within specified limits, and to detect deterioration.

Hidden failure. A failure which is undetectable during operation by the operator/crew.

Hidden function--

a. A function which is normally active and whose cessation will not be evident to the operating crew during performance of normal duties.

b. A function which is normally inactive and whose readiness to perform, prior to it being needed, will not be evident to the operating crew during performance of normal duties.

Incipient failure. A deteriorated condition that indicates that a failure is about to occur.

Indenture levels. The item levels which identify or describe relative complexity of assembly or function. The levels progress from the more complex (system) to the simpler (part) divisions.

Inherent design level of reliability. That level which is built into the hardware item, and therefore is inherent in its design. This is the highest level of reliability that can be expected from the hardware item. To achieve higher levels of reliability generally requires modification or redesign of the hardware item.

Glossary (continued)

In-service reliability. That characteristic of design and installation that will ensure a system's (equipment's) capability to operate satisfactorily under given conditions for a specified period of time.

Integrated logistic support (ILS). A unified and iterative approach to the management and technical activities necessary to--

a. Cause support considerations to influence requirements and design.

b. Define support requirements that are optimally related to the design and to each other.

c. Acquire the required support.

d. Provide the required support during the operational phase at minimum cost.

Interfaces. The systems, external to the system being analyzed, which provide a common boundary or service and are necessary for the system to perform its mission in an undegraded mode; for example, systems that supply power, cooling, heating, air services, or input signals.

Lubrication & servicing. Any act of lubricating or servicing an item for the purpose of maintaining its inherent design operating capabilities.

Maintenance levels. The basic levels of maintenance into which all maintenance activity is divided. The scope of maintenance performed within each level must be commensurate with the personnel, equipment, technical data, and facilities provided.

Maintenance planning. One of the nine principal elements of ILS. Includes development of the maintenance concept, reliability and maintainability parameters, repair level determinations, maintenance requirements, and supply support essential to adequate and economical support of the system/equipment. Planning becomes more detailed as the system/equipment progresses through the acquisition cycle.

Maintenance process. A procedure used to determine maintenance requirements and may contain many maintenance tasks.

Maintenance tasks. An action or set of actions required to achieve a desired outcome which restores an item to or maintains an item in serviceable condition, including inspection and determination of condition.

Glossary (continued)

Manpower. The total demand, expressed in terms of the number of individuals, associated with a system. Manpower is indexed by manpower requirements, which consist of quantified lists of jobs, slots, or billets that are characterized by the descriptions of the required number of individuals who fill the job, slots, or billets.

Marginal failure. A failure which causes minimal injury, property damage, or system damage which will result in mission delay or mission degradation. Special operating techniques or alternative modes of operation involved by the loss can be tolerated throughout a mission but shall be corrected upon its completion. This is the same as SHSC 3.

Minor failure. A failure not serious enough to cause injury, property damage, or system damage but which will result in unscheduled maintenance or repair after completion of a mission. This is the same as SHSC 4.

Mission abort. The termination of a mission prior to completion because the failure cannot be repaired within 30 minutes by the on-board basic issue load list.

Nonoperational effects. Failure effects which do not prevent aircraft operation, but are economically undesirable due to added labor and material cost for aircraft or shop repair.

Objectives. Values, or a range of values apportioned to the various design, operational, and support elements of a system, which represent the desirable levels of performance. Objectives are subject to tradeoffs to optimize system requirements.

Operational check. A task to determine that an item is fulfilling its intended purpose. Does not require quantitative tolerances. This is a failure finding task.

Operational effects. Failure effects which interfere with the completion of the aircraft mission. These failures cause delays, cancellations, ground or flight interruptions, high drag coefficients, altitude restrictions, etc.

Operational scenario. An outline projecting a course of action, under representative operational conditions, for an operational system.

Preventive maintenance. The care and servicing by personnel, for the purpose of maintaining system/equipment safety and reliability levels, through systematic inspection, detection, lubrication, cleaning, etc.

Redundant system. A system composed of two or more components, below major item level, either of which is capable of performing the same mission or function independently of each other.

Examples--

1. Two launchers in a Hawk battery are not a redundant system. The launchers are considered major items.

2. Two hydraulic pumps in an aircraft, one primary and the other secondary are considered a redundant system since each can perform the same function independently of the other.

3. The tank turret system is operated with a redundant system. This first is electro-hydraulic and the second is manual.

4. The brake system and the parking brake system on a vehicle would not be considered redundant. The brake system function is to slow or stop the motion of a vehicle. The function of the parking brake is to hold a vehicle once it has stopped.

Reliability centered maintenance. A disciplined logic or methodology used to identify preventive maintenance tasks to realize the inherent reliability of equipment at a minimum expenditure of resources.

Scheduled maintenance. Periodic prescribed inspection and/or servicing of equipment accomplished on a calendar, mileage, or hours of operation basis.

Severity. The consequences of a failure mode. Severity considers the worst potential consequence of a failure, determined by the degree of injury, property damage, or system damage that could ultimately occur.

Single failure point. The failure of an item which would result in failure of the system and is not compensated for by redundancy or alternative operational procedure.

System engineering. The selective application of scientific and engineering effort to--

a. Transform an operational need into a description of system performance parameters and a system configuration through the use of an iterative process, e.g., definition, synthesis, analysis, design, test and evaluation, etc.

Glossary (continued)

b. Integrate related technical parameters and assure compatibility of all physical, functional, logistic support, and program interfaces in a manner which optimizes the total system definition and design.

c. Integrate reliability, maintainability, safety, human, and other such factors into the total engineering effort.

System/equipment. The item under analysis, be it a complete system, or any portion thereof being procured.

Threat mechanism. The means or methods which are embodied or employed as an element of a man-made hostile environment to produce damage effects on a weapon system and its components.

Trade-off. The determination of the optimum balance between system characteristics (cost, schedule, performance, and supportability).

Training. The structured process by which individuals are provided with the skills necessary for successful performance in their job, slot, billet, or specialty.

Undectectable failure. A postulated failure mode in the FMEA for which there is no failure detection method by which the operator is made aware of the failure.

Unscheduled maintenance. Those unpredictable maintenance requirements that had not been previously planned or programmed, but which require prompt attention and must be added, integrated with, or substituted for, previously scheduled workloads.

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